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ANALYSIS OF METHODS OF PREDICTING PIT WALLS AND WASTE DUMPS STABILITY

Palamar A.Yu., assistant, Laufer D.D., student

Kryvyi Rih National University

Abstract: The main methods of observation and forecasting stability of open-pit mining is given. Problems of geotechnical processes are extremely complex and multifaceted problem which solution is impossible without a multitude of scientific problems due to the general course of scientific and technological progress in the theory and practice of open pit mining. Based on studies of actual performance pits and dumps it was reasonably significant and important to predict, an important aspect of the prospects of slopes condition that is important for the duration of their service. As a result of the comparative efficiency characteristics of existing methods and controls, the basic advantages and disadvantages are made. Analysis of theory and practice on the methods and means of implementing the operation prediction of iron-ore deep pits, led to the conclusion about the necessity of modern technology use in all types of surveyor-geodetic work that will improve operational and surveying records of open pit mining and mining operations, effectiveness observations deformation and loss of minerals.

Key words: geotechnics, mining, pit, mining operations, surveys, geodesy, monitoring, prediction, stability.

Introduction. The introduction of new and existing automated methods of forecasting steady state of open-pit mining is a hot topic for the mining industry. Methods and tools that have been developed a few years ago are now outdated, they have been replaced by more accurate, more efficient, improved and automated ones. Today surveyor or geodesist is facing a problem of using the correct choice of method and the method of forecasting steady state of rock mass. Therefore, to overcome this problem it is proposed to perform a comparative analysis of existing methods of observation used in Kryvyi Rih basin (Kryvbas) enterprises.

Materials and Methods. Today there are many methods and automated control systems, all of which in one way or another perform the task. The labor market is represented by a large variety of modern devices for observing the steady state of mining. Powerful enterprises every day are seeking ways to improve and upgrade existing facilities for observations. However, the forecast assumes a reliable measurement of baseline data to assess future sustainability pits and dumps walls, part of which is to establish the form and position monitoring slip surface in rock mass based on it, by interpreting the results of the methods of monitoring the displacement of work rappers located on the sides of the berm of dumps and pits. The most significant deviation in the determination of the time of a possible shift or when determining the shape and position of the salient occur in the central parts, performance and impact of which can lead to errors in study design and assess the stability of pit walls and overburden dumps slopes.

Results. Selecting the most accurate method of predicting the stability of pit walls and dumps that require minimal cost to use is one of the most important parts of the process of observations of the rock mass. Monitoring of slopes is carried out while performing mining operations to front pit contours. In fact, status of monitoring slopes is a process of compliance between current measurements of geotechnical parameters and pre-determined rules. The main objective of observations is - detection mechanism landslides and setting the most important parameters of slope deformation. The observations reveal the full amount of the aggregate effect of factors that affect the stability of slopes and pits sides. Efficiency and quality prognosis depend on the speed and accuracy of obtaining background information on surface displacement near pit walls massif.

In Ukraine, experts use a wide variety of methods for predicting the steady state of open pits, the main ones are: visual; engineering and surveying; engineering and geophysical; instrumental; geotechnical; engineering and hydro geological; hydro geological methods [1-2]. The analysis of modern methods of monitoring and

control, as mining regions in enterprises of Krivbass allowed forming a table, with which there is an opportunity to review a comparative analysis to ensure credible decision on the choice of a particular method [3-4]. There has been established a comparative description of methods of forecasting a steady state of open – pit mining and presented in Table. 1.

Table1. Analysis of efficiency of monitoring the stability of pits and dumps walls methods

Method	Method's advantages	Method's disadvantages	Characteristics of the method
visual	allows to estimate the field of use of the results of instrumental, geophysical and engineering, geological condition of slopes	only part of the complex methodology of slopes conditions study	fixation method is visible on the surface manifestations of abuse for slopes, the character of massif fracturing, water occurrence and effects of blasting
surveying-geodetic	gives a quantitative estimate of the slope deformation, reveals the nature of early strain that allows you to make prediction about its development over time	requires special tracking station	fixation method is to obtain quantitative and deformation patterns on the surface of slopes and deep massif on the results of measurements of horizontal and vertical displacement of sediments
engineering and geophysical	allows fast and efficient way to find the beginning of geotechnical processes	does not give a definitive statement about the state of the slopes, it can be done only on the basis of geological and hydro geological observations	method gives data to determine the development of deformation processes and their speed
instrumental	developed hardware, some technique work, counting system of coordinates, a high degree of safety work	used only to monitor the stability of profile lines on the walls	fixation method is to obtain quantitative and deformation patterns on the surface of slopes and depth of massif on the results of measurements of horizontal and vertical displacement of sediments
engineering and geological	acquires a leading role in the formation of soft and rock dumps on the weak base	their use depends on the degree of rocks compaction in the dumps	fixation method is to change the distribution of physical fields (electric, magnetic, electromagnetic, etc.) related to the presence of hidden slope slide, changes in physical, mechanical and physical properties of rocks
engineering-hydro geological and hydro geological	rapid determination of properties of rocks, comparison of actual performance with calculated, document cases deformation of slopes and necessary amendments in the design and development of specific additional measures to ensure the slopes stability	lack of experience in the application for the task, the need of additional research for such cases	methods for determining the position of the depression curve in the rock mass, measurements inflows of groundwater in areas of leak and perform measurement of steam pressure

The complex tectonic structure in a number of mining regions, caused by a significant increase in the depth of development requires fundamentally new devices to monitor landslide of rocks, characterized by high accuracy in forecasting and their relatively simplified design. This is due to the specifics of these works. High precision requires improved speed performance prediction of mine workings stability and balance of records of industrial reserves. The current practice of mining enterprises in Kryvbas shows that at the moment of observation and measurement of the pits are performed by using tachometry, leveling, use of GPS systems, etc. [5, 6].

The devices used for geotechnical monitoring of open-pit mining in the territory of Kryvbas are: electronic total stations; GPS systems; remote methods (digital terrestrial survey); optical and electronic levels; electronic stations; laser rangefinders; laser scanners; radar control systems.

The qualitative leap towards a tool for building 3D models was made with the advent of no reflected measurement systems and of development based on these three-dimensional laser scanning systems. The use of these techniques allows obtaining significant advantages both in technological and economic aspects [7].

Practical application of high-satellite GPS receivers to determine the strain state of open pits, allowing you to shoot, which significantly reduces both the time of operation and processing results. This was the first step in developing basic

methodological approaches of GRS filming for the control of strain state of open –pit mining. The use of GRS in Kryvbas pits allows: to abandon the inclusion of the relevant lines of observation stations supporting frame close to the observed rock mass (reference point differential correction may be at a distance of 5 kilometers from the line profile), which in turn increases accuracy of measurements; significantly expands the boundaries of the study area, the impact of mining operations, which ultimately allows you to study the deformation of the upper crust caused by human activity at a upgraded level [8].

Ordering of technical means for monitoring of geotechnical steady state of open-pit mining is shown in Fig. 1.
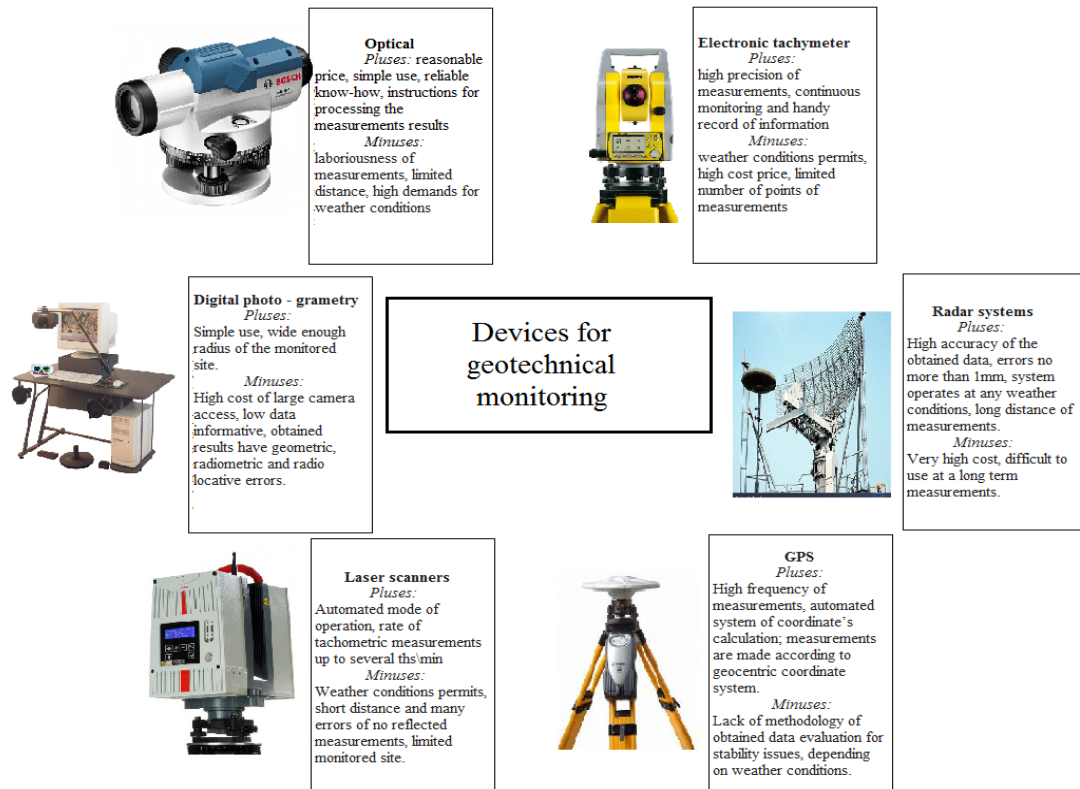
Optical
Pluses: reasonable price, simple use, reliable know-how, instructions for processing the measurements results
Minuses: laboriousness of measurements, limited distance, high demands for weather conditions

Electronic tachymeter
Pluses: high precision of measurements, continuous monitoring and handy record of information
Minuses: weather conditions permits, high cost price, limited number of points of measurements

Digital photo - grametry
Pluses: Simple use, wide enough radius of the monitored site.
Minuses: High cost of large camera access, low data informative, obtained results have geometric, radiometric and radio locative errors.

Devices for geotechnical monitoring

Radar systems
Pluses: High accuracy of the obtained data, errors no more than 1mm, system operates at any weather conditions, long distance of measurements.
Minuses: Very high cost, difficult to use at a long term measurements.

Laser scanners
Pluses: Automated mode of operation, rate of tachometric measurements up to several ths\min
Minuses: Weather conditions permits, short distance and many errors of no reflected measurements, limited monitored site.

GPS
Pluses: High frequency of measurements, automated system of coordinate's calculation; measurements are made according to geocentric coordinate system.
Minuses: Lack of methodology of obtained data evaluation for stability issues, depending on weather conditions.

Figure 1. Devices for geotechnical stability conditions monitoring of open-pit mining

Nowadays, the most common method of correction of the satellite signal is the method of differential correction. This method is based on the accumulation of data for differential correction at the base, which consists of a receiver with antenna, computer and related software. Mobile GPS receiver also collects data in its own memory in a volume sufficient for further correction information. After work completion the data base and the data from mobile GPS receiver are jointly processed using special software.

The use of radar control systems (SSR) - Ground Probe can be called the latest science and technology achievement in this field. The purpose of monitoring using radar surveillance systems is to reduce the risks of disasters and reduce their possible effects due to early detection of displacements and deformations of the earth's surface at the surveyed areas.

Conclusions. To improve the efficiency of supervision, deformation in mining regions of Kryvyi Rih special place is devoted to the effective implementation of new devices for automation mining processes. The task of improving the methods of measurements and interpretation of fractured rocks in the pit walls, mines, dumps, boreholes is quite relevant today. Overall, the forecast of stability of open-pit mining, surveying observations of rock slides is the most reliable because it is based on objective information on the status of mining massif. But its use is faced with production and economic problems to get real deformation data of rock slopes. This necessitates the involvement in the field and desk surveying of

modern surveying equipment to monitor the stability of benches, pit walls and dumps.

The introduction of new information and measurement systems on territory of Kryvyi Rih led to automation of most processes and ease of processing. So, important is the creation of the system of automatic stability control boards in pits and dumps, some of the first systems have already been developed, passed laboratory tests and are ready to being implemented in mines. In terms of "cost - effectiveness" and the quality of the information, the use of GPS technology to obtain information about the strained state of rock mass to predict their steady state is far the most appropriate.

Problem of stability control of by-walls massif in Kryvbas pits can be solved only on the basis of an integrated approach that includes all components of the solution of problems and issues that have been discussed in this article.

References

1. Dolgikh L.V., Dolgikh A.V., Malenkiy M.N. (2006). Modern methods of survey work in the open pits [Sychasni metody znimalnych robit na kar'erach]. *Journal of Kryvyi Rih Technical University*, **13**, 48-51.

2. Instruction on observations of deformations of the walls, benches and slopes of dumps in open pits and the development of measures to ensure their sustainability. Lviv: VNIMI, 1971.

3. Demyanov V.V., Prostov S.M., Hyamyalyaynen V.A., Sydeltsev S.V., Sorokin R.Y. (2006). Technical and Informational support of the system of automated stability control of pit-walls [Technicheskoe iinformatsionnoe obespechenie systemy avtomatizirovannogo kontrolya ustoichvosti bortov karerov] **3**, 113-117.

4. Genik A.A. Chernenko V.N. (2003). The study of deformation processes on Zagorskaya GЄS by satellite methods [Issledovanie deformatsionnych protsessov na Zagorskoi GES sputnikovymi metodami]. *Geodesy and Cartography*,**2**, 27-33.

5. Bolotnikov A.V., Romanenko A.A. (2010). The use of GPS-technology in surveying, geodesy, open pit mining[Primenenie GPS technologiyv marksheidersko geodezicheskom obespecheniiotkrytych gornych robot]. *DP "NDGRI"*, **52**, 35-41.

6. Genike A.A., Pobedinskii G.G. (1999). Global satellite positioning system GPS and its application in geodesy [Globalnaya sputnikovaya sistema opredeleniya mestonachodzeniya GPS i ee primenenie v geodezii], Moscow: Kartotsentr Geodezizdat.

7. Methodical instructions on observations of deformations of pit walls and dumps, interpreting the results and forecast stability [Metodicheskie ukazaniya po nabludeniyu za deformatsiyami bortov razrezov i otvalov, interpritazii ich rezultatov i prognozu ustoichivosti]. Lviv: VNIMI, 1987.

8. Petrakovskii S.J. Application of stereo photogrammetry methods and PHOTOMOD Lite program surveying measurements practice. [Primenenie metodov stereofotogrametrii i programmy PHOTOMOD Lite v praktike markcheiderskich izmereniy].

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3D MODELING IN THERMAL POWER ENGINEERING

Zamytsky A.V., ScD, Professor, Shepelenko M.I., student.

Krivyi Rih National University

Abstract. In scientific work the basic principles of 3D-modeling of thermal power projects are considered. Addition to traditional visualization methods of computation will not only accept the principle of the maximum and external similarity of equipment-forging, but also optimize the analysis of heat and mass transfer processes occurring in this equipment. As a visualization object it was chosen steam generator brand E-75-42-440 CT, it is equipped with the necessary pipelines within it and fixtures, as well as devices for sampling and boiler feed water, saturated and superheated steam This unit is designed and manufactured in the block, as boiler design allows installation stature blocks or assembly in mounting blocks.. To create a 3D-model of the steam generator E-75-42-440 CT it is used software KOMPAS-3D ASCON. In the article are identified advantages and disadvantages of the software in the design of heat and power facilities based on the analysis of its capabilities. To consider export of models from medium COMPASS to other CAD (computer-aided design) systems, allows you to create rendering model; perform animations, as elements of the equipment and heat-exchanging processes occurring in this model equipment; conduct an in-depth analysis of Heat and Mass Transfer-processes.

Keywords: 3D modeling, thermal power, engineering, CAD, steam generator

Introduction. In studying and designing of heat and mass transfer processes common means of computation are widespread. Usually such studies performance becomes a complex task that requires a significant amount of time and effort, especially if there is a need to investigate the processes of evaporation in real industrial facility heating equipment, which usually has a complex structure and considerable dimensions. Complex calculations and their obdurate character do not let to pay attention to the main purpose of the design - the perception of complex heat and mass transfer processes occurring in the heat engineering equipment, and the relation between parameters and characteristics. The complexity of the overall computing resources makes it impossible to carry out in-depth research, optimize the various parameters and characteristics, create or modify the actual heat equipment. Development of adequate physical models, is possible in the transition from complex calculations to computer-aided design systems.

Materials and Methods. Design and drawing is strict information area that requires precise graphical and descriptive instructions. Terms of drawings and specific disciplines (architecture, mechanical electricity, process, geodesy, structure, construction, etc.) are transferred from traditional drawing on the board into automated drawing [1].

In today's production computer-aided design (CAD, computer aided design) is widespread, which allows you to reduce time and money of design processes and increase the accuracy of the processes and processing programs, that reduces the cost of materials and processing time due to the fact that the processing modes are also calculated and optimized using EOM. Technical support CAD is based on the use of computer networks and telecommunication technologies of personal computers and work stations [2].

Computer-aided design can significantly reduce subjectivity of decisions to improve the accuracy of calculations, select the best variant for implementation based on rigorous mathematical analysis of all or the most of the variants of the project with the evaluation of technical, technological and economic characteristics of the production and operation of the proposed facility [3].Currently three-dimensional modeling is not widespread, mathematical modeling of the process of heat and mass exchange is often used.

Results. As the modeling object we have chosen the steam generator E-75-42-440 CT. To create a 3D-model we used software KOMPAS-3D of ASKON Company. Offered 3Dmodel satisfies dimensional characteristics of the steam generator E-75-42-440 CT, namely the combustion chamber completely shielded pipe $Ø60×3$ mm to 100 mm on the side, front and rear walls. On the side wall of the furnace there are 2 burners. Superheater - vertically spaced coils, two-stage, made of pipes $Ø42×3$ mm. Number of coils - 18. The lateral

spacing tubes - 75 mm, the location - the corridor. Economizer - Steel, Smooth pipe, coiled, staggered pipes Ø32×3 mm. The lateral spacing tubes - 75 mm, a longitudinal - 55 mm. Air heater - tube, vertical, staggered pipes Ø40×1,6 mm. The lateral spacing tubes - 60 mm, a longitude - 42 mm [4].

Approximate parameters: the nominal steam capacity of 75 t / h; the working pressure in the boiler drum 44 kgf / cm^2; operational pressure at the out let of the super-heater 40 kgf / cm^2;

Superheated steam temperature 440°C; flue gas temperature of 180°C; hot air temperature of 190°C [5]. Its geometry is a set of complex curved surfaces, holes, chamfers and rounding (Fig. 1). Each commissioned has a copy of the operation of the steam generator and has a number of (approved) deviations from the drawing sizes, which are recorded into the passport of the steam generator.
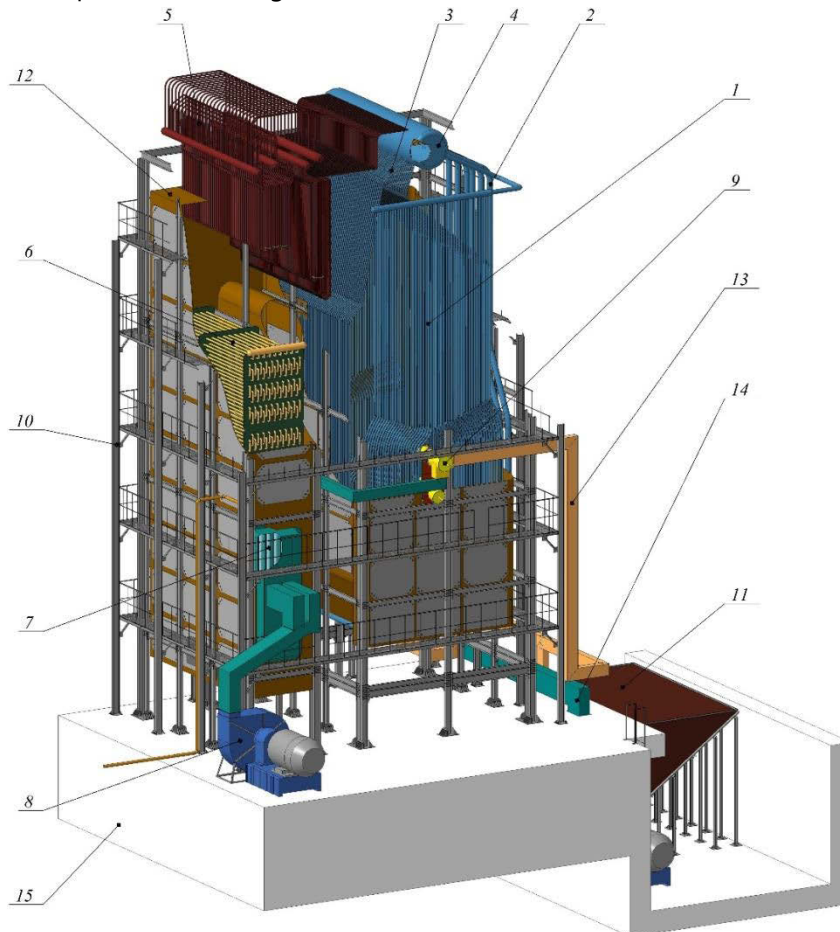

Figure 1. Sectional drawing 3D model of the steam generator E-75-42-440 CT:
1 - front-line screen pipes; 2 – stand pipe furnace tubes; 3 - side-wall tubes; 4 – drum separator; 5 –steam heater; 6 – the economizer; 7 – air pre heater; 8 – draft blow installation; 9- burner; 10 - frame; 11 - bunker coal-air mixture, 12 – walling of the steam generator; 13 – the pipe line of coal-air mixture; 14 – air pipe; 15 - foundation.

The problem in the design of the model is the proximity of mathematical approximations in operations with mathematical models of complex geometric objects: arcs of circles, spines; curved surfaces and "solid" bodies. Line based on points, surfaces - on the support lines and the creation of the body is based on surface creates a closed space, truncating the "extra". We are talking about operations such as the creation of complex lines

and surfaces, cutting them into pieces, the underlying commands such as "New item", "Create assembly", "Operation extrusion", "Cut extrusion", etc. [6].

Some approximations are replaced by others, errors accumulate and lead to the fact that smooth, but dissected, and surfaces appear like small ledges. Such defects prevent further operations and could lead to complete failure in

their performance, to hang a program or the end of its work. A significant amount of work was carried out with the help of the library "Pipelines 3D". Pipe systems are modeled by automatic means, or manually, the construction of the pipeline on the trajectory coordinate points, the location of which can be calculated from the dimensions given in the passport data of the steam generator [7].

The second, and the most important problem when creating a model - creation of a unified system of hollow pipes and tanks, the closure of the tube bundles into sewers, pipes placed in the tube sheets (Fig. 2).
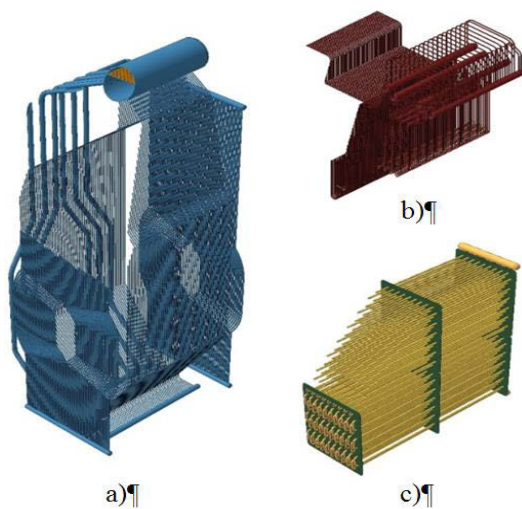

Figure 2. Pipe system 3D elements of steam generation system E-75-42-440 CT *a*) furnace screens; *b*) steam super heater; *c*) water economizer

Geometric operation can be performed without problems, sometimes there are problems when creating a final element mesh, or the apparent success of its creation, the appearance of the final elements, degenerate or nearly degenerate. To avoid this problem, you must minimize the amount of dissection operations; it is desirable to abandon the mat all. It is quite possible in block principle to create geometry. Large enough to create a characteristic blocks (Fig. 2) on which operations are only a few blocks are joined into a single hollow tube system.

To construct a 3D model of the core of the steam generator, the main goal was to perform it as close to the size of the drawing, which recorded and entered into the passport of the steam

generator. It is necessary to impart the desired strength and configuration of model steam generator units, which allows a 3D model of the steam generator as a basis for the study of different heat-exchange processes and calculations of materials strength. For creation a 3D model of the steam generator framework is largely used library «Metal 3D»is largely used [8]. This standard library, which is included in the package program COMPASS -3D, you can quickly and accurately simulate the metal structure, the dimensions of which recorded and entered into the passport of the steam generator (Fig. 3).
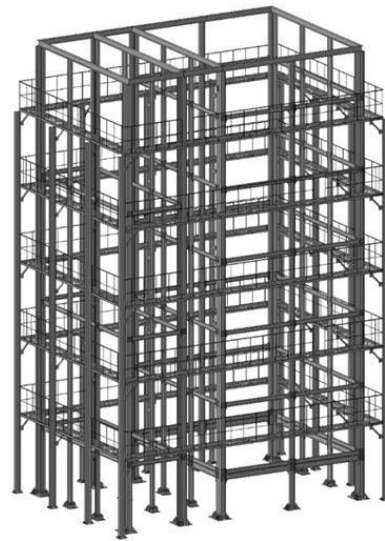

Figure 3. 3D wireframe model of the steam generator E-75-42-440 CT

Figure 4 shows a 3D geometric model of the steam generator E-75-42-440 CT, created with the use of recommendations on the basis of documentation of the unit. After finishing work on the 3D geometry of the steam generator and cleaning it from the "extra" it may be that the final element mesh refuses to be created for the entire model automatically. There are many reasons for it. Usually the automatic creation of 3D final element mesh is first based on the layout of all the edges, and then on each surface, and then, using the grid as a supporting surface, fill the volume finite elements. When the operation is successful, the optimization network nodes move in order to get better network performance. Layout options can vary.
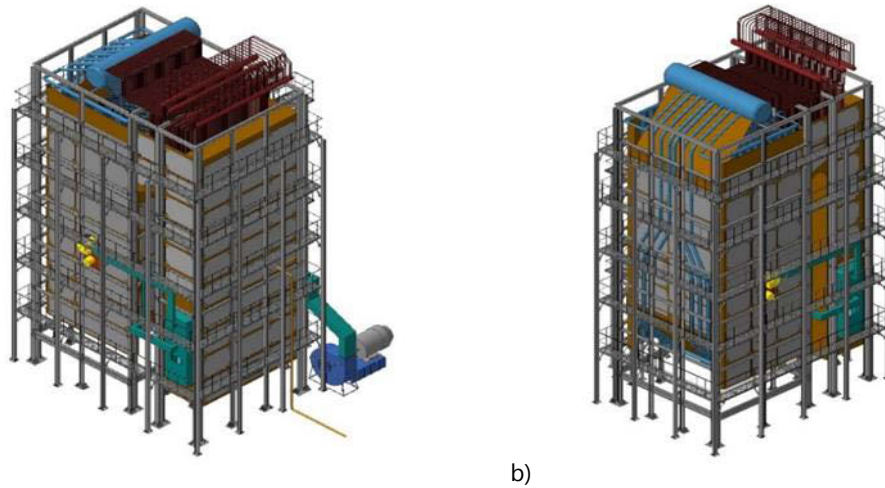
Figure 4. 3D model of steam generator: a) isometric projection XYZ; b) isometric projection ZYX

This 3D model of steam generator E-75-42-440 CT, is built by a student of the group TEP-11 SIHE "Krivoy Rog National University" M.I.Shepelenko led by, Professor O.V.Zamytskyi. The model is part of the project "energy block of thermal power plants", which won the first place in the "heavy" weight class engineering - more than 1000 items, at the XII competition "Future professionals of computer 3D-modeling", which was held in St. Petersburg, 2014 (Russia).

3D models are developed in COMPASS 3D environment can be imported into other environments CAD (ANSYS, Solid Works, etc). System, except it allows the computer to create the rendering of the model; animate as processes that occur in the unit and moving parts, and most important - to conduct studies of the physical processes occurring in the unit [9].

System ANSYS / Metaphysics, ANSYS / Mechanical, ANSYS / Professional ANSYS / FLOTRAN let us solve problems of heat transfer. The basis of thermal analysis in ANSYS is a heat balance equation, based on the law of conservation of energy. (Details are in the ANSYS Theory Reference).The last element solution obtained by using ANSYS, determines the temperature in the nodes, which are then used to obtain other thermal quantities. The program ANSYS allows to expect all three types of heat transfer: conduction, convection and radiant heat exchange. [10]

Using Solid Works also allows us to solve the problem of heat transfer. The main functional

limitation of thermal analysis module COSMOS works is that the temperature of the environment effects the convection and radiation does not depend on the temperature state of the model. During steady-state calculation it consciously constant, and in unsteady calculation can vary only under the control of the user. However, the surface characteristics (face and body surface itself) - the coefficient of heat transfer, radiation and heat flux and power - may depend on the temperature. Dependence is described by a broken line passing through the points defined by the user. [11]

The program allows you to play the effect of changes in heat transfer properties in the area of the mating parts. It may be due to the presence of the adhesive layer, imperfect contact. Function Thermal resistance (thermal contact resistance) allows us to refine the calculation and significantly reduce the dimensionality of the problem. The Help system provides indicative values of contact resistance for a number of materials with different surfaces. [11]

It is impossible in calculating the surface models to take into account the temperature distribution along the shell thickness in COSMOS works. Therefore, when you specify a temperature sufficient to assign it to one side of the shell. If you still try to make it different on opposite faces of a single surface, then the program will recognize the last entered value. [11]

Conclusions. Thus the use of 3D models as a basis for the study of thermal power facilities

allows linear, dynamic and thermal calculations to solve contact problems, conduct geometrically non-linear calculations and optimization; to solve the problems of radiation heat transfer; the non-stationary and stationary modes of heat and mass transfer.

In future it is planned on the basis of the model steam generator E-75-42-440 CT to create a physical model of heat-mass exchange and hydro-processes in the boiler (water circulation, the combustion process, the process of vaporization), and to simulate other processes occurring in the TPP equipment of power generation.

References

1. Zhadaeva A.G. AutoCAD. Detailed with pictures manual. Moscow: Best Books, 2006.

2. Kvetny R.N., Bohach I.V, Boyko A.R., Sofina A.Y., Shushura A.N. Computer modeling of systems and processes. Methods of computation. Available at: http://posibnyky.vntu.edu.ua/k_m/t1/zm1.htm

3. Babicheva A.F., Esaulov S.M. Computer-aided design of electromechanical devices. Kharkiv: KNAME, 2009.

4. Ushakov S.G., Muromkin Y.N., Shelygin B.L. Heat-span design calculations of boilers with natural circulation Ivanovo, 2004

5. Yasaveev H.N., Laptev A.G, Farahov M.I Modernization of Converting units for carbon contain mixture. Kazan: Publishing "Fan", 2004.

6. Bolshakov V.P., Boshkov A.L., Sergeev A.A. 3D-Modeling in AutoCAD, KOMPAS-3D, SolidWorks, Inventor, T-Flex. Saint Peterburg: Peter, 2011.

7. Magomedov A. (2009). Pipe lines 3D – in three steps. *Series Metal*, **6**, 84-87.

8. Zykov A. Metalworks 3D. (2009). Learning new Annex to machine building scaling ASCON/ CAD and Graphics, **1**, 85-86

9. Sokolov T.Y. AutoCAD 2009 for the student. Teach Yourself. Saint Peterburg: Peter "Teach yourself", 2008.

10. ANSYS 5.7 Thermal Analysis Guide, Available at: /http://orange.engr.ucdavis.edu/Documentation12.0/120/ans_the.pdf

11. Alyamovsky A.A. COSMOSWorks. Bases for design of structures for durability in SolidWorks environment. Moscow: DMK Press, 2004

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POTENTIAL INVOLVEMENT OF INFORMATION TECHNOLOGY TO IMPROVE RELIABILITY OF CONVEYOR SYSTEMS

Kalinichenko Yu. P, PhD., Associate professor, Drabchuck A. M., post-graduate

Kryvyi Rih National University

Abstract. The authors deal with topics need to bring the latest information technologies in the development of a system for collecting conveyor belts during the emergency failure of the latter. Also, the authors analyze the possible ways and approaches to the implementation of high-accuracy mathematical models of simulation processes capture conveyor belts catchers during emergency rush belt during operation of the conveyor. Also, considerable attention is paid to the analysis of factors affecting the durability of the conveyor belt, as well as the identification of random negative impacts on the conveyor belt.

The authors try to identify areas for further research and develop theoretical component modeling of capture belt during its break, and theoretically define the areas of some practical values that affect the process of collecting conveyor belts when it is broken. Indicated further areas of research give authors an idea of the order of magnitude that will be obtained during field studies, as well as provide an opportunity to focus on the most important factors and trends in the processes of capture. In this paper the authors present their vision of the future theoretical research for the thesis.

Keywords.

Introduction. Computer technologies in the last 50 years have made a huge step forward. Even 60 years mankind has used computers for sending humans into space, and now - using personal computers are able to calculate the complex processes of the medium and tension in different designs. With appropriate skills even one person is able to create a revolution in solving specific problems. Recently, more and more involved in computers and specialized software for designing machines and components. Computer simulation helps save a lot of time in solving any engineering problems.

However, the main obstacle is that relatively small number of specialists has specialized software at the right level. This is due primarily to the fact that our country is in the role of catch-up. In developed countries, almost all development stages are modeling and improvement of technical and geometrical characteristics by the software. That is, every detail, every unit, each unit initially projected collected, tested, improved in the computer environment, artificial environment, which is capable semulate computer program. And only then, when all the characteristics meet the requirements of the project, when all the parts and components are most effective - and start making real collection unit.

In our opinion, it is an advantage and immediate reason for the need of general implementation method of computer simulation units prior to their making and implementation process at work.

In the world for several decades use computer technology for the development of conveyor systems, modeling behavior belts, remote monitoring its status in real time prediction of failure on a given conveyor system in real time, and so on. At present the most relevant precision mathematical computer models are able to provide comprehensive data on the system with the provision of tables, graphs, charts, tables, and enough to make an accurate prediction of future and stability of the system [1-9]. The most progressive elements of the design is the analysis by FEM method (taper elements), and linear or nonlinear analysis [11-12] It allows you to more accurately calculate and consider the behavior of any details.

The introduction of new computer simulation in the process of developing new and improving existing systems capture conveyor belts is one of the priority directions in the design of a continuous transport. This method will work out hypotheses and theories about the appropriateness of different modes capture belts different designs trap. At the same time, will develop mathematical models of the behavior of

the end of the belt at the time of the cliff and its behavior at the time of capture.
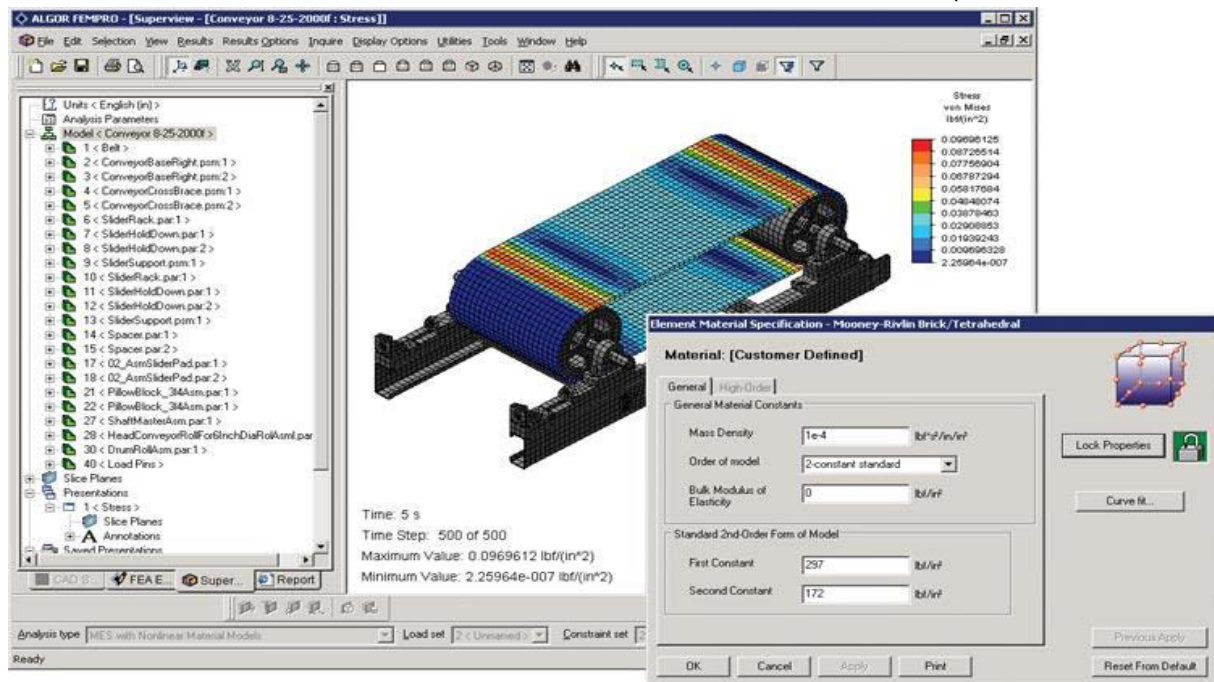

Figure 1. The illustration of of load distribution in the conveyor belt performed in Algor MES software [11]

Materials and methods. During operation of conveyor systems one of the most important elements of the design to ensure trouble-free operation of conveyor belts are traps. Even after emergency impulse conveyor belt traps help to minimize the loss of the goods and the costs of liquidation damages that may cause flow breed. Therefore, the design and operation of the trap is made in accordance with the requirements of the mining industry, namely the ability to trap quickly stop conveyor belt that comes after her emergency impulse.

Simplicity of design helps reduce maintenance costs, and the correct approach to design - simple design has less chance of rejection or failure of its individual elements.

An important and difficult step in modeling systems capture belt when creating emergencies in the pipeline is multifactorial nature of stress, the stress of various types, kinds and sizes, as well as the difference in the material conveyor belt and its pond. Among the most significant is that the trap must work tape as the tape at break, and at its opposite movement together with the load at emergency stop drive belt. Also, the trap should ensure suspension of the belt in such a mode in which the load on the belt did not wear a destructive trap design and components of the tape. In addition, the design of trap should be as simple as possible, in the most effective and the most simple and plain operation.

Results. However, the correct choice of the location of traps on the conveyor pond plays an important role in the efficiency of the assembly line. Installing traps near the old belt tensioning station, performance is reduced to almost zero. This is because the loaded conveyor belt is rarely breaks in the area tensioning drum. In this area there are only belt tensile force of tightening station and a small amount of ore loaded to the feed. In the area around the drum clamp can be torn worn belt or ribbon unlikely influenced by factors such as emergency failure of individual elements of the pipeline, which will create excessive tensile force, and so on.

Set traps in the area near the drum drive belt is the most appropriate. This is due to the fact that in this area on the belt are much harder than in the tension zone near the station. Here repeatedly increasing pulling force from the drive drum creates torque; amount of material transported, which is distributed over the entire length of the tape reaches the maximum value that creates a large longitudinal tensile force in the

tape. Also in this case, not least between the belt and sagging supporting rollers under load. Overcoming resistance that creates slack tape multiplied by the length of the conveyor and the degree of load latter are too large dissipative tensile force, affecting the state of the conveyor belt. The essential point in the selection trap placement is to determine the number of traps. In practice on conveyor lines may have one or more traps. In addition, the types of traps, in which part of the overall design of the device includes previous responses to break the belt, an important factor is the choice of installation location relative to the main structure trap.

This is because the increase in the number of traps increases the overall system to counteract the effects of the possibility gusts belt. But at the same time, increase the number of leads to increased costs for their service and installation immediately.

So, localization zone greatest stress on the conveyor belt during operation, and therefore the most likely places impulse conveyor belt is a major factor in deciding where to install traps or trap system for conveyor pond.

We should not forget that the raw material is transported on conveyors mining complex also wears tape. This is due to abrasive materials, sharp edges pieces of rock, the effect of corrosion factors belts from raw materials and vibrations generated in the film during download this material from the hopper.

The combination of all the aforementioned factors ensures that the belt wears out faster than envisaged performance. If these factors worn and torn tape in the area by far the largest load on it, namely in the area of the drum drive belt.

It should be noted that "zone near the drive drum" is sufficiently vague concept. To date, very little research conducted which would be designed to search for and select the optimal location of traps tapes.

Directly capture process also significantly affect the belt. Depending on the speed of capture, the nature of the efforts that are part of the trap on the belt, the amount of cargo and its

physicomechanical properties and load tape may behave differently.

Thus, considering the aggregate belt and load may make concluded that the speed and nature of catching mainly affect the process of catching the condition of belts with load after the final closure of the conveyor belt.

Given the theoretical aspect catching belt speed range can be seen in the following ranges: from almost instantaneous capture from belt by applying maximum effort to capture it with a slow gradual increase efforts admiration. The selection of optimal parameters capture is a key factor proper operation trap. Very sharp capture belt loaded bulk cargo, it can provoke deformation, causing the elastic wave. The kinetic energy of this strain can be transmitted load and sprinkle it on the conveyor gallery.

On the other hand, the relatively slow belt capture trap may not be fast enough that the belt will cause slippage between working bodies trap and its withdrawal from the area of capture. In this case, loaded with belt will move in the direction of tension station, causing the destruction of structures belt.

Among presay examples of emergencies that require development process simulation systems capture conveyor belt fit of the cross is catching bands and stop the conveyor during longitudinal cut belt. The phenomenon of longitudinal cuts belt observed in places loading conveyor by contact with a sharp object, which is obtained from a bootable device is compatible with the main flow of bulk cargo This factor is particularly dangerous because it delayed at stopping the conveyor belt can be cut along its entire length with a forced replacement last .

Empirical optimal selection options in conjunction with the latest methods of computer simulation - the only way to ensure the highest possible efficiency factor and reliability traps conveyor belts.

However, empirical method of selection parameters can give only approximate results. To determine the expected present research results in Table 1 which will determine the most promising areas.

Such a wide margin of tolerance specified time because is unknown how long it takes to capture a conveyor belt on a particular line, and I shall proceed capture process that would not damage the tape. It was mentioned above.

Consider the nature of super-fast capture. At this speed capture clear advantage is that the conveyor belt loaded with what appears to be moving in the opposite side of the main direction of the conveyor stops almost instantly. At first glance belt loaded with bulk materials virtually no time to move in the direction of stretch and break station construction pipeline.

However, with this character trapping may occur in longitudinal elastic wave section of belt as a result of the sudden seizure of the latter. This elastic wave can be so powerful that can throw small- and medium-bulk material space with belt. At the same time, the sharp capture conveyor belt can destroy the surface layer cover belt and can cause excessive load on the trap design.

Quick capture mode can also be damaging to the surface layer of belt and shoe contact surfaces for traps. As in the previous capture mode belt likelihood of unwanted destruction system catcher Feed is very likely. On the other hand, a gradual capture belt is preferred for its surface layer and the contact surfaces trap.

From our point of view, moderate capture mode is the best. This is due to the fact that in this mode the balance of forces between surfaces catching shoe trap and forces that try to pull the tape from the zone of capture is optimal. We believe that in this mode trapping layer is preserved cover belt to continue the whole contact area shoe trap. Also, the likelihood of elastic waves in the film is low enough to not take this probability into account.

In slow motion capture significantly increases the likelihood that performance capture system is lower than required. That increases the likelihood that trap just do not have time to work properly. In this case, it is also possible partial operation systems: boots catcher make it closer to each other and touch the belt, holding it slightly. However, decreasing speed down the tape is already very large and due to inertial forces belt with a load of sliping capture zone.

Very slow capture mode included in the table are more checks for all possible capture. Clearly, in this case, the probability of triggering traps partial or complete refuse is very high. The system can capture tapes just do not have time to squeeze the tape to the desired strength.

Conclusion. As a conclusion we note that we have outlined future directions in the study of modes of capture on tape conveyor systems. Theory is defined most likely value of time and modes of trap mechanism prior actions.

References

1. Harrison A. (1979), A new development in conveyor belt monitoring, Mach & Prod. Engineering, **32**, 17.

2. Harrison A. Remote NDT monitoring of belt damage and safety factor analysis, 9th ICBMH, Newcastle: NSW, 2007.

3. Harrison A, Dynamic Measurement and Analysis of Steel Cord Conveyor Belts, PhD thesis, Australia:The University of Newcastle, 1984

4. Roberts A.W., Papaliski D., Harrison A. The Friction and Tension Characteristics on Driving Drums of Conveyor Belts, Proceedings of 12th Intl. Power and Bulk Solids Handling Conference, Chicago, USA, May 1988.

5. Harrison A., Barfoot O. (1989). Modelling the Effect of Take-Up Ucation on Conveyor Belt Performance, Third Intl. Conf. On Bulk Materials, Storage, Handling and Transportation, Newcastle: IE(Aust), June 1989, 119-123.

6. Hardson A. (1988). Stress Distribution in Steel Cord Belts with Cord Plane Defects and Inlaid Repairs, Intl. Jnl. Of Bulk Solids Handling, **8**(4), 443-446.

7. Matuszewski P. Condition Monitoring in BOT KWB Belchatow mine. Diploma thesis Mining Faculty, Wrocław, 2007.

8. Gladysiewicz L, Krol R. Condition Monitoring of idlers. 1st Conference on Mechanisation of Mining Industry, Institute of Mining Mechanisation Silesian University of Technology, 2002.

9. Beavers D., Morrison D., Rea D. Non-Linear Model for Dynamic Analysis of Conveyors. *Sinclair Knight Merz*, Available at: http://www.skmconsulting.com/ Site-Documents/ Technical-Papers/Non-Linear-Model-for-dynamicanalysis.pdf.

10. Michael L. Bussler President and CEO ALGOR, Inc. Pittsburgh, PA, Available at: http://www.algor.com/ news_pub/tech_reports/2003/beyondlinear/

Khorolskyy, I.M. Dynamika lantsyuhovykh system i zamknutykh konturiv mashyn neperervnoho transportu Lviv: Lvivska politekhnika, 1999

12. Jurdziak L. Failure analysis of textile and Steel cords belt used in KWB "Turów mine", Industrial Transport, 2002

UDC 378

OPEN EDUCATION SPACE: COMPUTER-AIDED TRAINING OF THE FUTURE ENGINEER-TEACHER

Bakum Z, Sc.D (Ped), Professor, Tkachuk V., assistant

Kryvyi Rih National University

Abstract. One of the challenges facing higher education is training of graduates for professional activity in the information society. The solution of this problem is connected with students' competence formation in the field of computer science, computer engineering and information and communication technology. Activation of the formation process of "engineer-teacher" profession requires solving the problem of computer-aided training of specialists in the field of engineering and pedagogy, taking into account global experience, as well as issues of training specialists, that are common to the national higher school. In the article the computer-based disciplines for the field of training 6.010104 "Vocational Education (according to specialty) have been analyzed as professional. The attention is focused on the open education space as one of the means of optimization of these subjects teaching in view of modern popularization of continuous open access to the educational process.

Key words. open education space, computer-aided training, engineer-teacher, "Vocational Education".

Introduction. In the context of the information society the development open education is becoming as relevant as ever, and information and communication technology, distance, electronic, mobile, cloud-based learning form its basis.

Open education involves the creation of common information and education environment of open access, teaching resources of educational institutions (educational plans, programs, methodical recommendations (for laboratory, practical, independent, course, qualifying works), lectures, examinations, the subject of reports, a list of recommended books and etc belong to its repository. Furthermore, the results of researches, projects, cooperation with professionals from other countries that promote the integration of Ukrainian science to the common European and global intellectual space are related to such databases.

Over the past few decades, the system of knowledge generation and transfer has radically changed, and their scope has increased to a great extend. When training at the university it is impossible to prepare a person to the professional activities for life. Nowadays about 5% of theoretical and 20% of professional knowledge is updated annually. The solution of the problem is transition to lifelong learning, where basic education must be supplemented with additional programs and serves as the basis [3]. According to V. Bykov [2], open

education and open educational systems provide use of open learning environment, formation of its means and technologies, with computer-based tools and information and communication technology (ICT) playing the leading role. On this basis information and communication platform for open education is based, thereby informatization, as a social phenomenon is an important factor and modern tool of innovative education development.

Materials and methods. Information and education environment of open education is investigated by domestic and foreign scientists (V. Bykov, C. Zdioruk, A. Ishchenko, M. Karpenko, V. Filipov). They develop the system of educational process with information support and Internet documenting of institutions of different accreditation levels and forms of ownership. So, V. Filipov marks the following principles of open education: open educational planning, that is the freedom of drawing up an individual program of study by selecting courses from the system; freedom of timing and pace of training selection, i.e. the admission of students to universities throughout the year and no fixed terms of training; freedom in the choice of place of study: students can be physically absent in the classrooms most of the study time and they can choose where they learn; transition from the principle of "education for life" to the "lifelong learning" principle; free development of personality, that is an important

factor; whereas the classical model of education allows strict rules, that unify the human personality [7]. Engineering and pedagogical education as the highest concentre of common professional training system for the industry or several industries is in the context of open education development. The features of this system are combination of training with students' professional training, that's why the engineering and pedagogical education is referred as the system where the laws of pedagogy and manufacturing are interrelated. The term "engineer-teacher" has a dual character: on the one hand, it is an "engineer of the appropriate specialization" on the other – "teacher" that combines psychological, pedagogical and methodological knowledge and skills [4].

A well-known foreign scientist of professional formation of the engineer-teacher personality Ye. Zeer says: "Engineer-teacher" does not mean "engineer" plus "teacher", it leads to the formation of a new concept "[5, p. 16].

Results. Therefore, the training of future engineer-teachers is in the mastering of modern methods of independent research and analysis of any information using information and communication technology. Formation of IT skills should meet the requirements of educational qualification characteristics (EQC and EPP) of engineer-teacher that summarizes the content of education and reflects its objectives [6]. The main components of computer-aided training must be shaped so that the specificity of the subject area of future professional activity reflects in specific application tasks. Analysis of computer-aided training for the specialization "Vocational Education (according to specialty)" (see Table. 1).

The analysis of state educational standard of the training 6.010104 «Vocational education (according to specialty) » as a source of the content of future engineer-teachers' professional training allowed us to define the scope of informative disciplines and their place in forming students' readiness to professional activity.

The amount of computer-based disciplines in different specializations of the training «Vocational Education (according to specialty)» shows that students' readiness to professional

activity is purposefully formed in specialized and computer-based disciplines.

Analyzing the state of specialists' readiness for the vocational education system, standards of higher vocational education, educational and methodological basis of this training, we can state that nowadays such training occurs in 35 specializations [8]. Among analyzed (15 specialties) one of them is straight directed to the specialists' training in information and communication technologies – «Computer technology». We should accentuate the analysis of correlation of the portion of disciplines which can be attributed to computer-aided training, common quantity of disciplines which are the parts of the curricula of certain specializations of Vocational education. The computer-based disciplines' portion was determined with correlation of credits according to the curricular of educational and qualification level «bachelor».

So the analysis of students' computer-aided training in the specialization «Vocational Education (according to specialty) » provides a basis to assert that the general amount of computer-based disciplines – 29 for 15 specializations, according to the curricular only two disciplines are provided («Informatics and Computer Science», «Engineering and Computer Graphics»). Mentioned disciplines are the parts of natural and scientific training, their aim is to form and develop knowledge, abilities and skills necessary for usage of computer machinery and means of information and communication technologies in the future professional activity. Accordingly, for the specialization «Vocational Education» the portion of computer-based disciplines is about 3-5 %, except the specialization «Vocational Education. Computer Technology», where curricular provide for 14 disciplines relating to the computer-aided training (it's about 30 % from the general educational load).

Conclusion. So, computer-aided of future engineer-teachers provides for additional opportunities of choosing the alternative courses and teachers, which is ensured by means of the integration of educational and methodological and personnel supply of educational institutions into

the common databases available via Internet. In   other words, in the open education space.   .

Table 1. The scope of computer-based disciplines in different educational program specialization on the field of training "Vocational education (according to specialty)"

№	Discipline	Metrology, standardization and certification	Life and Labour Safety	Electrical Engineering (all specializations)	Computer technology (all specializations)	Electronics	Telecommunications and connection	Radio engineering	Welding	Mechanical engineering (all specializations)	Transport (all specialization)	Publishing and printing	Technology of textile and light industry	Food technologies	Design	Economics
1.	Informatics and Computer Science	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
2.	Engineering and Computer Graphics	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
3.	Computer Systems and Networks Information Security				■	■	■									
4.	Microprocessor and Microprocessor Systems			■				■	■							
5.	Automated Control Systems			■												
6.	Computer Design and Multimedia				■										■	
7.	Fundamentals of Circuitry						■									
8.	Theory of Automatic Control			■												
9.	Modelling and Optimization of Automated Control Systems			■												
10.	Systems of Information Processing and Transfer			■												
11.	Modern Robotic Complexes and Flexible Industrial Systems			■												
12.	Work Training				■											
13.	Ergonomics of Information Technology				■											
14.	Computer and Analytical Activity				■											
15.	Computer-Aided Document Science				■											
16.	Computer Technology in Educational Process				■											
17.	Applied and Web Programming				■											
18.	Design and Operation of Information Systems				■											
19.	Repair and Modernization of Personal Computers				■											
20.	Technology in Education				■											
21.	Peripheral Devices and Interfaces of Electronic and Computer Devices and Systems					■										
22.	Programming of Electronic Devices					■										
23.	Digital Circuitry					■										
24.	Database in Electronic and Telecommunication Systems and Networks						■									
25.	Telecommunications and Information Networks						■									
26.	Computer Science and Microprocessors in Telecommunication Devices							■								
27.	Basics of Information Theory							■								
28.	Technology of Graphic Information Processing											■				
29.	Applied Graphics											■				

References

1. The Why and How of Open Education. – The Netherlands: United Nations University, *UNU-MERIT CCG*, 2011.

2. Bykov V. (2010). Vidkryte navchaljne seredovyshhe ta suchasni merezhni instrumenty system vidkrytoji osvity [Open educational environment and modern network tools of open education systems]. Academic periodical of NPU n. Ser. 2 : Computer-oriented systems of education, **9**, 9-15.

3. Zdioruk S. Ishchenko A., Karpenko M. (2011). Formuvannia yedynoho vidkrytoho osvitno-naukovoho prostoru Ukrainy: optymalne vykorystannia zasobiv zabezpechennia vyperedzhalnoho rozvytku [Formation of open common educational and scientific space of Ukraine: optimal usage of the leading development support], National institute of strategic research., Available at: http://www.niss.gov.ua/ content/articles/files/ Science_ educational-e2f67.pdf

4. Zeer E. Professyonalnoe stanovlenye lychnosty ynzhenera-pedahoha [Professional formation of the engineering teacher's personality], Sverdlovsk: Ural university press, 1988.

5. Kankovskyi I. (2008). (2008). Engineer-teaching activities and its components. Problems of engineer training education, Kharkiv, **21**, 58-63.

6. Osvitno-profesiina prohrama pidhotovky bakalavra [v chastyni rozdilu zahalnoho navchalnoho chasu za tsyklamy pidhotovky, pereliku ta obsiahu normatyvnykh dystsyplin [Professional education bachelor-level program (in part of section of total study time according to the cycle of preparation, list of disciplines and range of pre-requisite subjects)], Kyiv: Ministerstvo osvity i nauky Ukrainy, 2010.

7. Fylyppov V. Tykhomyrov V. Otkrytoe obrazovanye – stratehyia XXI veka dlia Rossyy [Open education – the strategy of the 21st century for Russia], Moscow: MESY, 2000.

8. On the Approval of the List of the profiles of manpower training in higher educational establishments under the area (speciality) "Professional education (in profile)" (2010) : order № 705. Ministry of Education and Science of Ukraine. Available at: http://zakon1.rada.gov.ua/ laws/show/z0604-10

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SYSTEM OF AUTOMATIC CONTROL OF THE UNIFORMITY OF HEATING OF THE LAYER OF PELLETS ON A CONVEYOR ROASTING MACHINE

Lobov V.Y., PhD, Associate prof., Lobova K. V., student,

Kryvyi Rih National University

Abstract. Research in the field of creation of effective methods and means of automation of the process of firing pellets on the conveyor of the heating machine is an important task. To solve this problem, the structure of ATS uniform heating of the surface layer of the pellets, which uses a variable control of the cost of natural gas on each of the main burners. At the same time to run them apply flame the pilot burners operating on the principle of binary control (on, off). Throttle valves driven by a synchronous servo regulated gas flow to the main burners. Studies have shown that the use of such actuators with inverse negative correlation can accurately determine the position of the regulatory authorities. To control the gas flow to the pilot burner is sufficient to use valves with electromagnetic actuators, which are able to take only two fixed positions. The principle of operation of SAR is to maintain the temperature set points on the surface of the layer of pellets on user specified level. The temperature control is conducted on the basis of data obtained from four control points of the surface of the pellets. The basis of the draft automation APCS based on the functional diagram of the management process of burning pellets, updated material and technical base of the existing system of regulation, which uses modern primary transformers, large integrated circuits, specialized controllers and another element base.

Keywords. Automatic control, uniformity, pellets, conveyor roasting machine, heating

Introduction. As a result of the combustion of natural gas to pipeline heating machine changing temperature of the layer pellets, as this process affects the number of allocated heat. Due to the flow of warm air that enters the zone annealing zones of recovery and cooling, the heat from the combustion gas should uniformly distributed throughout the layer pellets. However, when the burner is probable uneven heating pellets, as areas that are under the direct influence of the burners receive more heat than the central layer of pellets. A similar situation also arises in non-uniform permeability layer pellets or change the velocity of the pallets heating machine, etc. [1-3]. In addition, the automation process iron ore oxidized pellets roasting in the oven conveyor kiln car to date is also the problem of energy savings, since fuel costs significantly affect the cost of the finished product.

Simple ways to save energy – is a reduction of the thermal conductivity of refractory materials, reducing their thermal inertia, and so on. In this area played a significant role in the use of heat, fencing designs fibrous materials and products based on them. Over the past 30 years in this direction was made quite significant discoveries. Reduce fuel consumption allows the use of modern burners and control systems, which provides for the possibility of active recirculation of combustion products and alignment furnace temperature field with a relative error of 5 °C.

Especially effective is a comprehensive solution to the question - replacing traditional fireclay bricks products based on fiber installation of radiation-convective energy recovery and use of modern burners with automatic fuel control system. The complex of these solutions can not only reduce fuel consumption by 20-25%, but also increase the productivity of the thermal unit to 20%. Among those using high fiber and products based on them, which are capable of withstanding high temperatures (1500 °C) and have low thermal conductivity, has created entirely new design of furnaces and application of modern primary converters, large-scale integrated circuits, microprocessors, controllers and specialized another element base, make it possible to equip the machine conveyor Lime latest System of Automatic Control (SAC).

The current state of automation conveyor heating machine does not fully identify the main thermal regimes of [3, 4]. Difficulty removing real performance temperature control burning in the layer of pellets cannot get controlled data that can be used to enter into the ACS process of heat treatment on a conveyor pellet heating machine. Today actively conducts research in the

development of effective methods and tools that will solve this problem [1-10].

The aim is to study the need for and development of the ACS, which provides uniform heating layer pellets along the width of the conveyor pallet in the oven.

Materials and methods. The proposed ACS smooth flow control using natural gas for each of the main burners. To start using their pilot flame burners that operate on the principle of binary control (on, off). The gas flow to the main burner (hereinafter simply burners) are regulated throttle, driven in synchronous servomotor movement [11]. The use of actuators controlled by negative feedback connection allows you to accurately determine the position of regulators. To control the supply of natural gas to the pilot burner valve enough to use with electromagnetic actuators that are able to take only two fixed position.

The principle of the CAP is to maintain the temperature set points of the surface layer of pellets on the user defined level. Temperature control is based on data from four control points pellet surface. In practice, the temperature reading is advisable to use partial radiation pyrometers "thermoscope-600-1S" [12]. Anchor points are selected uniformly distributed along the line connecting the centers of both areas of direct influence burners, with two extremes are away from the sides of the conveyor to prevent impact to show pyrometer temperature side bed [13]. Fig. 1, and an exemplary location reference points 1, 2, 3, 4 on the surface of the investigated area layer pellets. ACS is the input variable desired temperature at reference points. The initial values are the measured using a pyrometer temperature reference points in the surface layer of pellets.

Block diagram of the studied model is shown in Figure 2. CAP as well. In the above structural scheme as a control object selected model temperature distribution in the layer pellets described in [], but in practice this will take place real object management. The input SAR filed desired temperature satisfying technological conditions roasting pellets. Control element compares obtained from the measuring element temperature values at reference points of desirable

and generates control signals that carry information regarding changes in natural gas on the left and right burners. In accordance with these actuators, are synchronous servomotor, gradually change the position of regulators (throttle) on each burner, causing changes in the cost of gas. For optimum ratio "air-gas" depending on the cost of natural gas is regulated by the flow of air to the antechamber and directly up to the burners. On the structural diagram of the calculation of proportions "air-gas" is not shown, because the object model management believed that air enters the optimum for complete combustion of the fuel quantity.
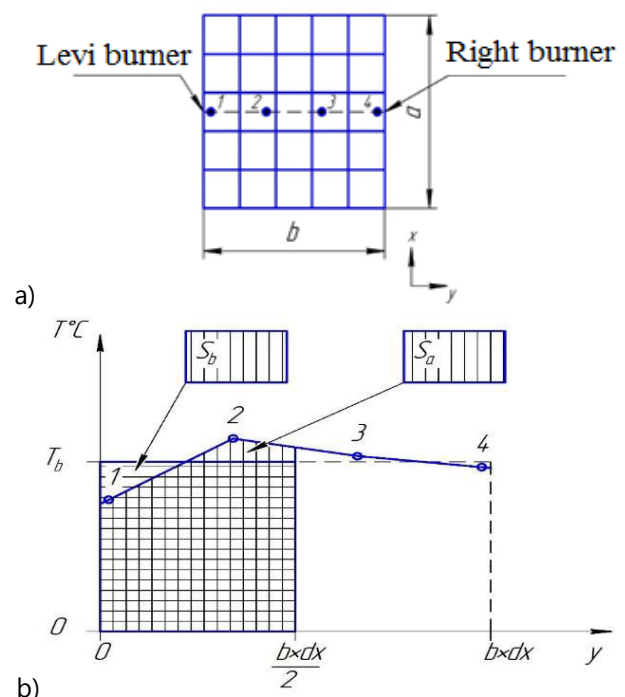

a)

b)

Figure 1. Location of control points on the surface layer of pellets investigated area (a)and presentation of measured values and the desired temperature of pellets in the zone of influence of the left burner as space and

(b)

As a result, combustion control output object temperature field is formed, some of which are fixed values measuring unit (group of four pyrometers). Measurement results re-sent to the control element. SAR has two independent circuits control the left and right burners, each of which individually regulated natural gas consumption. To ensure the stability of transients in control circuits used PID controllers. On the structural diagram regulators are not made in separate blocks, and are considered part of the general controls. Functional

diagram CAP uniformity of heating layer pellets is shown in Fig. 2b.

Control signals in both control circuits are formed based on the values of temperature control points: - on line left burner - control circuit in the right burner. The desired temperature surface layer of pellets is set at the entrance SAR value. Since the developed system contours to control each burner are the same and independent of each other, the only detail the formation of natural gas burner on the left.

To determine the error pellet temperature control in the area of direct influence of the left burner is necessary to calculate the difference between the expected and measured values of temperature. For this reason, will present the latest in a square shape, which are shown in Fig. 1b.

The figure is limited coordinate axes T and y, and direct $T = T_b$ and $y = \dfrac{b \cdot dx}{2}$ has an area S_b, whose value is proportional to the desired temperature pellets. According to the measured temperature at reference points 1 and 2, along the axis coordinates are known in advance, calculated values of the area S_b. Error value of the system ΔS_L calculated by the formula (1).

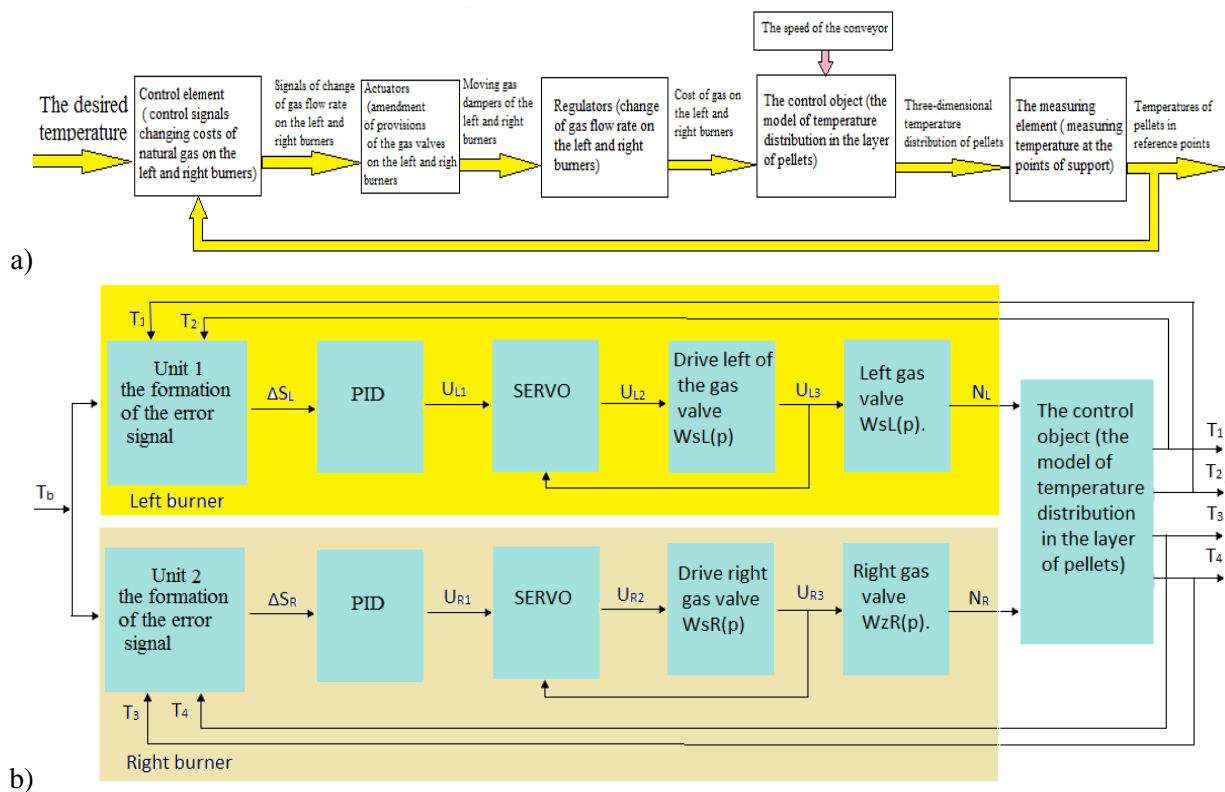$$\Delta S_L = S_a - S_b \qquad (1)$$

Figure 2. Structural (a) and functional (b) CAP schemes uniformity of heating layer pellets

The figure is limited coordinate axes T and y, and direct $T = T_b$ and $y = \dfrac{b \cdot dx}{2}$ has an area S_b, whose value is proportional to the desired temperature pellets. According to the measured temperature at reference points 1 and 2, along the axis coordinates are known in advance, calculated values of the area S_b. Error value of the system ΔS_L calculated by the formula (1).

$$\Delta S_L = S_a - S_b \qquad (1)$$

It should be noted that in case of equality ΔS_L zero temperature at reference points 1 and 2 does not necessarily correspond to the desired value, as calculated in the area S_a lack of temperature at point 1 offset its abundance in point 2 and vice versa. However, in this case the natural gas remain unchanged, because the uneven temperature field independently changed due to heat.

Based on the error adjustment ΔS_L PID controller generates a control signal U_{L1}, that the input block SERVO, which in practice serves an integral part of the synchronous servo, but for clarity in the scheme, he made a separate unit. SERVO forms the angle of rotation axis electric U_{L2}, whose value is measured in radians and varies that are able to provide a range of changes in the degree of openness flap U_{L3} from 0 to 100%. In the change of the angle of rotation of the principle of three positional regulation [15]. Box SERVO control is used for reverse negative communication, and therefore for its correct operation must get value the degree of openness flap U_{L3}.

According to the changes the angle of rotation U_{L2} electric gas damper left anther changes its position. Transfer function over $W_{SL}(p)$ described oscillatory link. Since the implementation of the CAP developed in the Simulink environment drive is given a separate unit with built-in libraries, it is not necessary to calculate the parameters of the forward transfer function. The initial value of the electric unit is openness flap that is determined by the U_{L3} and measured in percentage (100% - maximum capacity throttle).

Transfer function of the gas burner left flaps $W_{ZL}(p)$ can be represented as a proportional level of gain, corresponding to its maximum

capacity. According to the value of U_{L3} the output power flaps formed natural gas consumption N_L, m^3/h.

Similarly, the value is the formation of gas flow on the right burner N_R. However, in this case to calculate the errors of the system used temperature T_3, T_4. Formed natural gas consumption N_L and N_R the input control object that presented previously developed model of temperature distribution in the layer pellets [13].

The output of control object temperature is set at four reference points (Fig. 1) T_1, T_2, T_3, T_4. To determine the temperature change at the end of the time interval dt each block layer pellets, which are in the areas of direct influence of the left or right burners should use the formula:

$$\Delta T_L = \frac{Q_{KL}}{c_0 \cdot m_0 \cdot n_e} = \frac{K_e \cdot ККД_п \cdot N_L \cdot q_г \cdot dt}{c_0 \cdot m_0 \cdot n_e}, (2)$$

$$\Delta T_R = \frac{Q_{KR}}{c_0 \cdot m_0 \cdot n_e} = \frac{K_e \cdot ККД_П \cdot N_R \cdot q_г \cdot dt}{c_0 \cdot m_0 \cdot n_e}, (3)$$

where c_0, m_0− specific heat and the weight.

Depending on the speed of the conveyor pallet positions chosen for the study of horizontal lines gradually moved from the beginning to the end of the gas chamber. Schedule changes over time temperature distribution along the width of the conveyor belt on the surface layer of pellets in the gas chamber within the study given in Fig. 3.
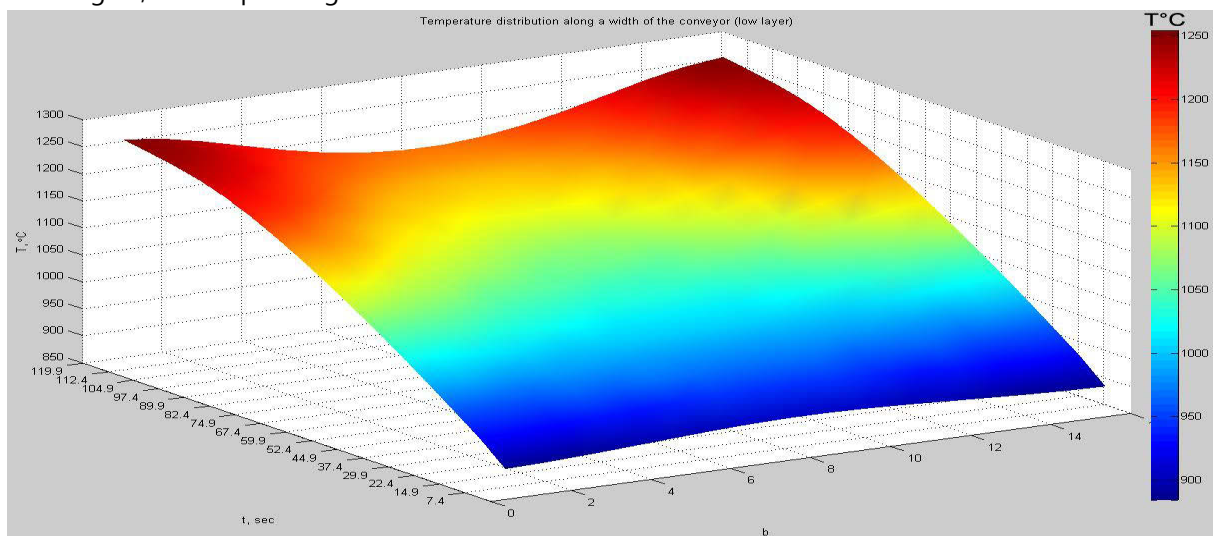

Figure 3. Schedule changes over time temperature distribution along the width of the conveyor belt on the surface layer of pellets in the gas chamber within the study

Conclusion. Developed ACS is designed to control the uniformity of heating the surface layer of pellets along the width of the conveyor pallet in the oven in a single gas-chamber. The system includes two independent circuits control the left and right burners, each of which is separately controlled natural gas consumption. Method of calculation of errors temperature control pellet was based on its geometric interpretation. To ensure the stability of transients used PID controllers.

As the measuring elements suggested to use a system of four partial radiation pyrometer "thermoscope-600-1S."

In developed ACS used smooth control of natural gas to the main burner and binary control - the pilot. Regulators are throttle. As actuators suggested to use synchronous servo. The basis of the change in the angle of rotation about the axis of the principle of three positional adjustment.

References

1. Efimenko Y, Popov L, Kuznetsov L, Kracht V, Intellectualization of management. Monograph. Stary Oskol: LLC "TNT", 2005.

2. Butkarev A.P., Butkarev A.A. Mayzel G.M., Nekrasova Ye.V. (2000). Povysheniye effektivnosti ASU gorno-metallurgicheskogo proizvodstva na osnove. Matematicheskiye modeli dlya upravleniya protsessom proizvodstva okatyshey na konveyyernoy mashine [Improving the efficiency of automation of mining and metallurgical production based. Mathematical models for process control pellets on the conveyor]. *Stal*, **3**, 10-13.

3. Yusfin Yu.S., Pashkov N.F., Antonenko L.K. Intensifikatsiya proizvodstva i uluchsheniye kachestva syrykh okatyshey [Intensification of production and improve the quality of green pellets], Moscow: Metallurgy, 1994.

4. Butkarev A.A. (2008). Metodologiya issledovaniya i optimizatsii konstruktivnykh i rezhimnykh parametrov teplotekhnicheskikh skhem obzhigovykh konveyyernykh mashin dlya termoobrabotki zhelezorudnykh okatyshey s tseyu povysheniya proizvoditel'nosti, snizheniya raskhoda topliva i elektroenergii. Pechnyye agregaty i energosberegayushchiye tekhnologii v metallurgii i mashinostroyenii: Proceedings of IV international scientific conference [The methodology of the study and optimization of constructive and regime parameters of thermal schemes roasting conveyor machinery for heat treating of iron ore pellets in order to increase productivity, reduce fuel consumption and electricity. Kiln and energy-saving technologies in metallurgy and machine-building] (April 3-4, 2008 MISA). Moscow, p. 90.

5. Tsaplin A.I. Nikulin I.L. Modelirovaniye teplofizicheskikh protsessov i obyektov v metallurgii [Modelling of thermal processes and objects in metallurgy] Perm. state. tehn. Univ., 2011.

6. Krivonosov V.A., Pirmatov D.S. Povysheniye effektivnosti upravleniya obzhigom okatyshey v konveyyernoy obzhigovoy mashine. Proceedings of the scientific-technical conference of information technologies in metallurgy and machine building. March 26-28, 2013 Dnepropetrovsk: NatsMetAU 2013, 50-52.

7. Bokovikov B.A., Markin V.M., Naydich M.I. (2002) Matematicheskoye modelirovaniye dinamiki protsessa obzhiga okatyshey na konveyyernoy mashine. [Mathematical modeling of dynamics of firing pellets on a conveyor machine]. *Metallurgical heat engineering*. **8**, 25-31.

8. Ruban S.A., Lobov V.Y. (2008). Rozrobka printsipív keruvannya temperaturnim rezhimom protsesu vipalyuvannya kotuniv z vikoristannyam prognozuyuchikh ANFIS-modeley [Development of principals of control the temperature regime of burning process of pellets using ANFIS-forecasting models *Electronics. Computer Science. Control*, 69-74.]

Pirmatov D.S. Matematicheskaya model' teplovoy obrabotki okatyshey v obzhigovoy mashine [A mathematical model of heat treatment of the pellets in the burning machine]. Proceedings of the All-Russian Conference: New technologies in the research, design, management, production of HT-2010 Voronezh 2010, 88-89.

10. Ruban S.A, Lobov V.I. (2008). Kompyuterne modelyuvannya algoritmu optimal'nogo keruvannya temperaturnim rezhimom vipalyuvannya kotuniv z vikoristannyam prognozuyuchikh ANFIS-modeley [Computer modeling algorithm for optimal control of the temperature regime of burning pellets using ANFIS-forecasting models], Journal of Kryvyi Rih National University, **21**, 150

11. Servo drive. Available at: http://ru.wikipedia.org/wiki/Сервопривод.

12. Fiber stationary infrared thermometer Thermoscope-600-1S partial radiation. Available at: http://www.infratest.ru/product/fixed/15.html.

13. Lobov V.Y., Kotlyar M.O. (2015). Modelyuvannya rozpodilu temperatur u shari zalizorudnykh obkotyshiv hazopovitryanoyi kamery v konveyernykh pechakh fabryky ogrudkuvannya [Simulation of temperature distribution in the layer of iron ore pellets in the gas chamber conveyor furnace pelletizing plant], Scientific Bulletin of National Mining University, 2

UDC 681.513.6:622.7:622.34

CREATING THE EQUIVALENT CURRENT OF ASYNCHRONOUS MOTOR WITH CONTROL ACTION MODULATION

Maksymov M., Phd, Associate professor, Philipp J. B., Phd, Associate professor,

Rybkin R. O., M.d. student

<u>*Kryvyi Rih National University*</u>

Abstract. Based on the fact that asynchronous motors go out of service for different reasons (through the overloads, adverse environmental conditions, low quality of power supply and so on) the necessity of carrying out of complex repairs was determined. As a result, it's possible to re-exploit the engine for a long time. The most weak point of electric motor during the repair works was identified. Considering the previously known publications that indicate the possibility of research real characteristics of repaired motor, there was provided the qualitative analysis, including existing deficiencies that would be reduced with help of the proposed system. Consequently, several solutions are proposed for motor windings electromagnetic energy change that help to load the motor excluding the possibility of mechanical influence to the shaft. These circumstances are substantiated by the formulas of the frequency, voltage and torque change. The graphs of artificial and natural mechanical characteristics with all work points indication are given for representation of electric motor full load cycle. The system was simulated with full cycle of loading and the results are presented in the form of phase coordinates oscillograms. The value of static load was chosen, according to the compliance terms of the rated current and sticking to nominal torque of the asynchronous motor. It was further defined and illustrated on oscillogram the loss power for showing benefit on the part of economy. As the research purpose was not only to produce a universal model, but also to make it economically profitable, the power loss was also determined and presented in an oscillogram form.

Keywords: asynchronous motor, frequency, the form of voltage, modulation, load, power, synchronous speed**.**

Introduction. As we know, asynchronous motors (AM) is one of the most common type of electrical motors, which are widely used in different fields [1, 5, 10]. That's why they are submitted high demands to reliability and operating time which increases responsibility of electrical repair enterprises. At repair AM the most vulnerable point in terms of changing its properties are electrical steel. The package of electrical steel changes its characteristics and integrity because of mechanical and thermal effects [2, 3]. The most influential factor is the process of temperature effects on the package during the roasting of windings for their removal. On another hand, quality of repair by technological parameters doesn't correspond to the level of production technology because of lack of universal equipment for research «random» motor [8, 9]. In this manner, the characteristics of fully repaired IM are different from the basic product, although exploitation is focused to the average factory indexes and in process of repeated exploitation breaks down soon [4, 6, 7, 11].

Materials and Methods. There are works in which the possibility of load AM without influence to the motor shaft by alternation operation modes of engine and changing the kinetic energy are considered [12]. Besides, there is a work based on the system thyristor voltage regulator – asynchronous motor (TVR-AM) in which load of AM was created under the influence of current and voltage harmonic components [13]. But the main disadvantages of this system are voltage distortion and the appearance of higher current harmonics in the network.

The main purpose of the article is the research of modulating type method by system frequency converter – asynchronous motor (FC-AM), which helps to realize current load of AM stator windings. On the other hand, the system must meet all requirements for ease of implementation, universality and efficiency of use.

Results. For changes the electromagnetic energy of windings, which is determined by the current of circuit magnetization, there are three approaches:

- influence on the shape of the voltage supply (amplitude modulation);

- influence on the frequency of the voltage supply (frequency modulation);

- influence on the shape of the field (polyharmonic loading).

Due to the fact that for the FC together with change of the supply voltage frequency we must regulate the supply voltage amplitude (for

avoiding the magnetic system saturation) – loading by the amplitude modulation and frequency modulation represents one process. Changing frequency process going according the formula

$$f(t) = f_0 + \Delta f \cdot sin(\Omega_\text{к} \cdot t),\qquad(1)$$

where f_0 - is the constant component of the frequency, Δf - is the increase of voltage supply frequency, $\Omega_\text{к}$ - is the angular frequency of changes the increase of the network frequency.

In this way, the synchronous speed of the motor field

$$\omega_0(t) = \omega_0 + \Delta\omega \cdot sin(\Omega_\text{к} \cdot t) = \omega_0 + \frac{2\cdot\pi\cdot\Delta f}{p} \cdot sin(\Omega_\text{к} \cdot t).\ (2)$$

The form of supply voltage described by the expression

$$U = U_0 \cdot sin(\omega_0 \cdot t) \cdot (k + m \cdot sin(\Omega \cdot t)),\ (3)$$

where U_0 - is the amplitude, k, m - are the modulation coefficients, Ω - is the angular frequency modulation of amplitude.

Then, the torque of AM, which develops in conditions of equality rotor speed and the main magnetic flux

$$M = M_1 \cdot cos(\Omega \cdot t) + \frac{M_2}{2} sin(2 \cdot \Omega \cdot t) ==$$
$$\Phi_1 \cdot I_{2m} \cdot cos(\Omega \cdot t) + \frac{\Phi_2 \cdot I_{2m}}{2} sin(2 \cdot \Omega \cdot t),\qquad(4)$$

where I_{2m} - is the amplitude of rotor current, Φ_1 - is the main flux, Φ_2 - is the amplitude of pulsating flux.
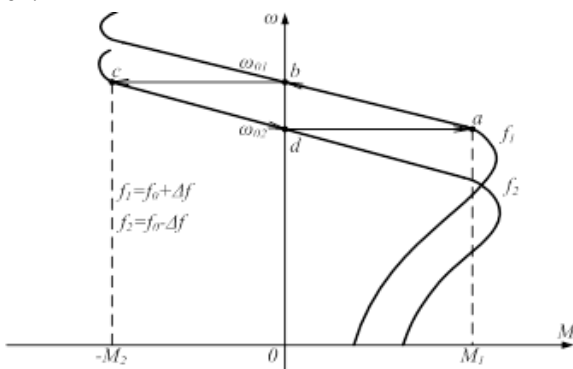

Figure 1. The cycle of load with frequency modulation of supply voltage

In case of frequency modulation, AM works in modes of motor and generator. The loading cycle is illustrated in Fig. 1. Point «a» is the nominal motor mode; the line «bc» is the generator mode with transmission to the artificial characteristic; the line «da» is the transmission to the natural characteristic; the line «ab» is the acceleration to the nominal speed.

Parameters f_0 and Δf are chosen so that the motor current and load torque should not extend nominal value (to avoid overheating). Asynchronous motor 4AM180S2 ($P_\text{н}$ = 22 kW, $n_\text{н}$ = 3000 rad/s) was chosen for simulation.
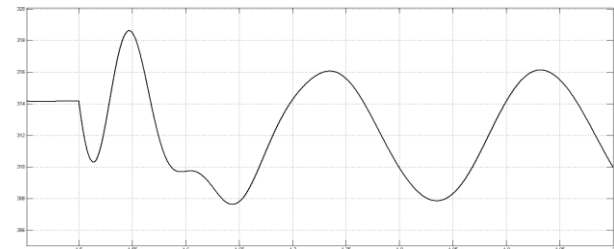

Figure 2. Oscillogram of rotor rotation speed with controlled influence 30+40·sin(31,4·t)
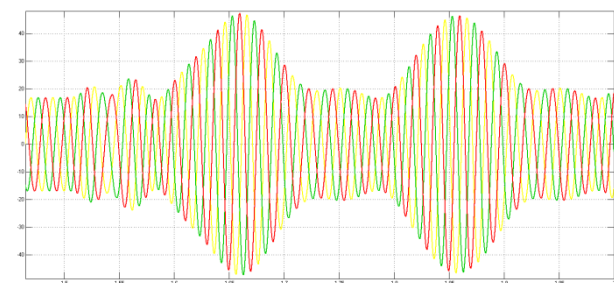

Figure 3. Oscillogram of the current in the three phases with controlled influence 30+40·sin(31,4·t)

Fig. 2 illustrates the oscillogram of rotor rotation speed with controlled influence 30+40·sin(31,4·t). One can see that rotor speed oscillations with a frequency about 5 Hz.

Fig. 3 illustrates three phase currents I_A, I_B, I_C. In this case the difference between the maximum values of the currents is:

- negative half-wave – 3,5%;
- positive half-wave – 2,6%;
- RMS currents value – 1,9%.

The RMS values of the load currents: $I_{\partial(A)}$ = 33,15 A; $I_{\partial(B)}$ = 32,91 A; $I_{\partial(C)}$ = 33,55 A, which is 76,8; 76,2; 77,7 % according to the nominal value.

It's necessary to note, that for modulation type load system the repetition period of current curve is the period of modulation, which is defined by

$$T_\Omega = \frac{2\cdot\pi}{\Omega},\qquad(5)$$

In this way, the effective value of the current, which determines the heating of AM, it is necessary to determine for the period of time T_Ω.

Forming of alternation sign torque is illustrated on fig. 4. In this case an amplitude of the torque is 89,64 N·m (positive part: 70 N·m; negative part: 19,64 N·m) at nominal value 70,06 N·m.
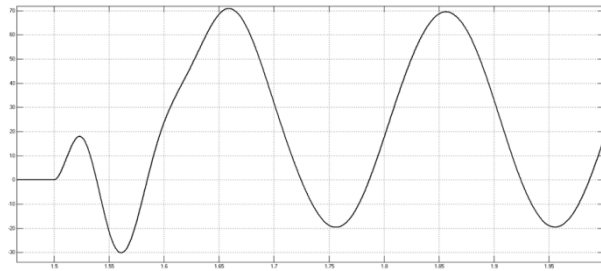

Figure 4. The torque of induction motor with controlled influence 30+40·sin(31,4·t)

Such factors are uniformity of phase loads, the possibility of rotor circle loading and economic effect determine effectiveness of using modulation type load for (FC-AM). If this system maintain the first two parameters, the problem of economy must be investigated.
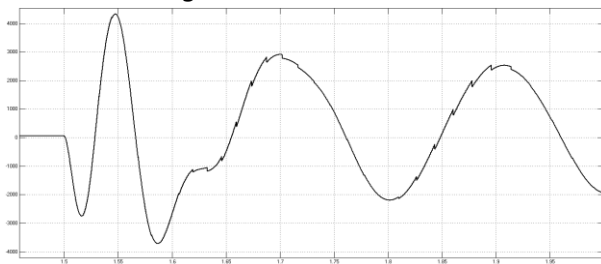

Figure 5. Loss of power in induction motor with controlled influence 30+40·sin(31,4·t)

The losses of power in AM depend on the load and defined as the electromagnetic energy and power on the motor shaft (fig.5). Moreover, the negative half-wave indicates the regenerative breaking.

Conclusions. On the basis of the researches we can conclude that with a help of using FC-AM system we may provide the load of «random» motor without influence to the shaft. Changing the frequency and amplitude of supply voltage make it possible to vary the level of stator circle load by the pulsed current. For confirmation the efficiency of the system it was conducted modeling of static load and determined the value of the loss of power which gives representation of the qualities of both economically and technically.

References

1. Goldberg O.D. Quality and reliability of asynchronous motors. Moscow: Energy, 1968.

2. Goldberg O.D., Abdullayev I.M., Abiyev L.N. Automation of the control parameters and diagnostics of asynchronous motors, Moscow: Energoatomizdat, 1991.

3. Gemke R.G. Malfunction of electrical machines. Lviv: Energoatomizdat, 1989.

4. Vinnikiv Ch.M. Technological calculations for repair AC motors, Moscow: Energy, 1970.

5. Kuybishev A.V. Reliability of asynchronous motors for general industrial use. Moscow: Publishing standards, 1972.

6. Gervais G.K. Industrial testing of electrical machines. Lviv: Energoatomizdat, 1984.

7. Kluev A.A. Automation testing electric motors average power. Compilation Electrical industry. Part «Electrical motors», Moscow: Informelectro, 1980, **8** (114).

8. Determination of motor quality through routine electrical tests. Soukup George C., *Ind. Appl. Soc.* 35 Th Annu. Petrol and Cnem Ind. Conf., Dallas. Tex., Sept. 12-14. 1988, 187 – 195.

9. Stack T.L. (1975). The repair and Maintenance of Rotating Electrical Machines, *Mining Technology*, **57**(662), 460-470.

10. Sieradzka M. (1972). Badania esploatacygneg trwalosci silnicow indukaginich. *Elektrotecknika. Buil. Inform.*, **26**(2), 61-71.

11. Stavrou A., Sedding H. G., Penman J. 2001. Current monitoring for detecting inter-turn short circuits in induction motors, *IEEE Trans. Energy Convers.*, 16(1), 32–37.

12. Rodkin D.I. Dynamic loading systems and diagnostic of electric motors with post-repair tests. Moscow: Nedra, 1992.

13. Maksymov M.M. et al. (2013). Formatting parameters of pulsating current of asynchronous motor with squirrel-cage rotor. *Mining info SHEI «Kryvyi Rih National University»*, **96**, 176-178.

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CONTROL OF THERMAL MODES OF TRACTION MOTORS AND SPEED MINE ELECTRIC LOCOMOTIVES

Sinchuk O., ScD,Professor, Guzov E., PhD, Sinchuk I., PhD

Kryvyi Rih National University

Chorna V., Assistant

Kremenchuk National University of Mykhailo Ostohradskyi

Abstract. Analysis and evaluation of quality indicators and functioning of existing control devices and temperature gauges speed mine electric locomotives, which are used in Electromechanical systems, traction motors DC series excitation in modern mines that are listed in the article. The authors found the main reasons for their low reliability. The method of non-contact control and protection of traction motors from impermissible exceeding of the temperature level in the cells, which requires creating the appropriate temperature sensors was proposed. The issues of speed control mine electric locomotives with the aim of improving health and safety of miners in underground transport were considered. The authors reviewed existing speedometers that are directly or indirectly connected with the rotary elements of the locomotive. The authors proposed a method for the contactless control and protection of traction motors from overheating and sensorless meter speed mine locomotive, the operation of which is based only on the electrical parameters of the electric traction motors.

Keywords: thermal modes, traction motors, speed mine, electric locomotives

Introduction. Iron ore raw materials (iron ore) produced from domestic mining enterprises, providing up to 70% of annual revenue is a significant component of the replenishment of currency reserves of Ukraine [1].

Meanwhile the cost of production of iron ore raw materials grows every year, which endangers this strategic competitiveness for the domestic economy of the export product [2]. The main component of the aforementioned odious process is the rising energy costs that make up more than one third of the total cash costs of iron ore, for all cycles of the technology of its production and delivery, regardless of the method of mining: open pit or underground (mining) [2]. Thus, unlike the pit, mining is characterized by the fact that electricity costs they make about 90 %, including up to 16% is the energy consumption for mine transport, a park which has about four thousand locomotives with outdated energy inefficient equipment.

Meanwhile, the second, no less important negative fact in the process of operation the school itself continued increase in material costs of mining enterprises for repair of electric rolling stock [2]. As follows from the analysis of damage items current operated Electromechanical traction systems (ETS) mine contact types of electric locomotives (Fig. 1 and Fig. 2), the dynamics of their injuries has evolved over the years.

It is important that the material costs for the repair of their components - traction electric motors (TEM) in the last decade the mines of Kryvyi Rih (so and other similar enterprises) increased almost 4 times and constitute more than 90% of all costs for repair of traction electric equipment [2].

This situation dictates the requirements for the need for additional analysis of this process and of developing sound and simultaneously real and modern proposals for withdrawal from defined position [3; 4].

Materials and Methods. Bringing the above-mentioned inefficiencies in the functioning ETS preferably to the optimum values by increasing its operational reliability, and trains in general, possible only with the construction and application of modern management systems with the capabilities of monitoring the condition of electrical and technological parameters of traction equipment. It should be understood that the traction electromechanical complexes of electric locomotives, as a basis for the structure of electrical equipment in general, and mine species in particular, are complex multifunctional systems, which have a significant number of parameters that must be controlled [3 - 10]. Based on the same results of failure analysis of the components of the

traction electromechanical systems mining electric locomotives and "severity" of the consequences of these moments, nevertheless the first step in building a control system parameters of the traction elements of the complexes should be the issue of control of those parameters that are most likely to cause damage to the traction components of electromechanical systems including TEM, and, therefore, the incapacity of the locomotive as a whole [6, 9 - 11].
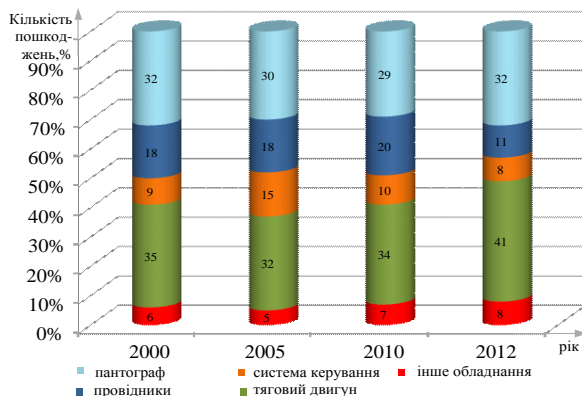

Figure 1. Dynamics on aggregate indexes of quantities of damage of the main elements of the traction electric equipment mine electric locomotives K14 used in iron ore mines of Kryvyi Rih iron ore basin
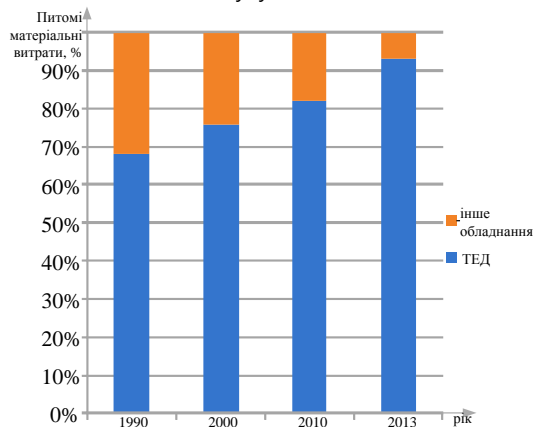

Figure 2. Change in unit material costs for the repair of traction electric equipment mine electric locomotives in the mines of Kryvyi Rih iron ore basin

In [5, 8] is proposed to control the temperature regimes of TEM. To do this, the author presents circuit solutions. In turn, in [9] present a new without touch method of speed control of train movement in the underground conditions in order to avoid exceeding the regulated value.

Meanwhile, the desired efficiency of the above funds for the conditions of the mining electric locomotives will be quite effective only when applied.

Consider each of the methods separately. This will stick to the tactics of building methods in order to determine the necessary parameters on the basis of already controlled in the structure ETS [10 - 13].

In turn, these parameters are the values of current, voltage and resultant heating elements TEM. As proved in [5, 9 - 10], it is based on the control values of the first two of the above components can be monitored and the third temperature TEM in the operation of the locomotive in flight cycles [11].

This sequence of approach to the tactics of the structure of the control system is based on the results of the analysis of the causes of the damage TEM during operation of the locomotive. And this is the influence of the superheat temperature [10] on the components of TEM, one of the anchors winding (Fig. 3). As the Fig. 3 shows, the temperature of the TEM with the work of the locomotive increases, which in conditions of lack of control that, will definitely lead to overheating of the windings and their subsequent destruction.

Second important parameter to control is the speed of the locomotive, which is governed by the applicable "Rules of safety" [10], and the excess of which leads to serious technological accidents and threatening the life of the miners. Meanwhile, for mine electric locomotives, with the specifics of their operation in underground mining, the solution vector of the above problems with their complexity lies in the direction of the development of control systems on the basis, primarily, of without touch funds [9, 10].

Study and development of circuit design efficient and reliable operation of sensorless control of thermal conditions of traction electric motors of direct current and the speed of mine electric locomotives.
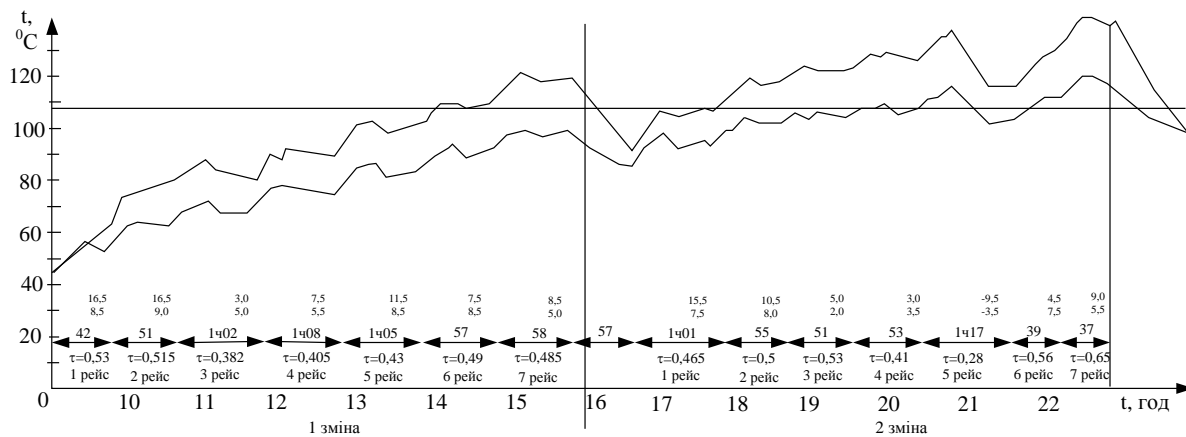
t, °C

120
100
80
60
40
20

16,5 / 8,5	16,5 / 9,0	3,0 / 5,0	7,5 / 5,5	11,5 / 8,5	7,5 / 8,5	8,5 / 5,0	15,5 / 7,5	10,5 / 8,0	5,0 / 2,0	3,0 / 3,5	-9,5 / -3,5	4,5 / 7,5	9,0 / 5,5
42	51	1ч02	1ч08	1ч05	57	58	57 1ч01	55	51	53	1ч17	39	37
τ=0,53 1 рейс	τ=0,515 2 рейс	τ=0,382 3 рейс	τ=0,405 4 рейс	τ=0,43 5 рейс	τ=0,49 6 рейс	τ=0,485 7 рейс	τ=0,465 1 рейс	τ=0,5 2 рейс	τ=0,53 3 рейс	τ=0,41 4 рейс	τ=0,28 5 рейс	τ=0,56 6 рейс	τ=0,65 7 рейс

0 10 11 12 13 14 15 16 17 18 19 20 21 22 t, год

1 зміна   2 зміна

Figure 3. Chart of temperature change of the armature winding of the traction motor DST-45/27 for two shifts of operation of the locomotive K14 (horizon 1045 m of Batkivshina mine, PJSC "Krivorizkiy Zalizorudniy Kombinat")

Results. As the experience of the operation of electrified ground transport and treatment system for continuous temperature control modes of operation TEM reduces failure 30 – 35 % , failure manifolds 2,6 – 3,3 times, all-round lights in them 3,1 – 3,7 times when there is a general decrease in headers 2,8 – 3,4 times [3]. In turn, the operation of TEM without the control systems of thermal regimes increases the number of their failures is 1,5 – 3,5 times [3].

Possible ways of temperature control TEM and build appropriate protections are:

- installation to the engine temperature sensors;

- the use of thermal relay;

- indirect assessment, which is based on the measurement of the resistance of the motor winding or the calculations of losses in the engine.

The most accurate, and now most often used, method is to measure directly the temperature of the windings or become active with the help of temperature sensors [13]. The main disadvantages of the method are:

- the necessity of embedding sensors in the motor windings that under operating conditions without dismantling;

- the necessity of output of the engine additional conductors, that in conditions of severe vibration may cause damage and failure of the protection system.

Second modern direction can be a thermal relay which, as research has shown, is rational to apply when defending TEM with constant or changing loads [13]. In excess currents continuous duty thermal relay trigger too quickly, which can cause a "race machine".

In addition, these relays are unsuitable to protect TEM from overheating, which is most typical for engines operating under ETS of mine electric locomotives [10].

Meanwhile, according to the studies of the authors [5; 9; 11], calculation of energy losses in TEM by analyzed period of time allows an indirect but fairly accurate assessment of the process of its heating.

When applying this method, the period of operation of the TAM is divided into intervals during which the current can be considered constant. In modern microprocessor on-board control systems of electric locomotives it is possible to implement direct assessment of energy losses by determining the equivalent current according to the expression:

$$I_{екв} = \alpha \sqrt{\frac{1}{T}\int_{0}^{T} I^2 dt} \ . \tag{1}$$

where α – is a coefficient taking into account the deterioration of the cooling of the engine at low speeds taken in the range 1,15 – 1,4 [5].

If the value exceeds the rated current continuous mode protection is triggered, feeding the signal to shut off the traction electric drive.

The average temperature of the winding TED can be determined from the magnitude of its resistance. The method is based on the real property changes in the resistance of the windings

TED as a function of temperature change. The temperature of the winding is determined by the expression [10]:

$$t_2 = \frac{R_2 - R_x}{R_x}(k + \tau_x) + \tau_x, \qquad (2)$$

where R_2, R_x – are support the windings, measured respectively in hot and cold conditions; τ_x – winding temperature in a cold state; k – is a coefficient of 235 for copper windings and 245 for aluminum windings.

As research has shown [3, 7, 10], the most dangerous and intense heat is generated in the armature winding TEM, but control its temperature accompanied by certain difficulties associated with brush contacts, since their resistance is unstable and can change dozens of times depending on the brand of brushes, burnishing, surface conditions of the reservoir and its temperature, speed, etc. To the same brush cover several collector plates. Therefore, a sufficiently accurate determination of the temperature of the anchor winding of the resistance is impossible.

However, there is another way to control the temperature on the resistance of the excitation winding (EW). This is possible based on the following considerations: the field winding of the traction motor is connected in series with the armature winding, and it is the same current flows; the windings are located in the same machine, so their heating and cooling related. This allows for temperature EW to accurately determine the temperature of the armature. Study the temperature distribution is carried out by the authors on a real bench, showed that while the maximum allowable temperature of the armature winding is heated at 25^0C higher than EW. Taken into account that the allowable temperature of the armature winding of the traction motor insulation of class F is 155^0C, and the maximum allowable for heating is 130^0C.

Therefore it seems only logical that despite the fact that the EW and allows a higher temperature, overheat protection TEM shall be activated when the temperature of the coil 130^0C. The temperature corresponds to the level of resistance [11]:

$$R_{130}^{Cu} = R_x \frac{365}{235 + \tau_x}. \qquad (3)$$

Fig. 4 shows a variant implementation of the protection circuit of the traction motors from overheating.

The average voltage U is removed from the EW through the circle, consisting of $R1 - R2$ and C that limits the voltage pulses at switching in the power range of the device that is being protected. The average value of the current I which flows through the EW, determined using a shunt RS. Configuring protection for a certain resistance and carry out the appropriate temperature adjustment resistor $R3$. Block protection device contains analog integrated divider which performs the function of division U_{cep}/I_{cep} - that is, continuously determines the amount of resistance of the windings. When the resistance value that corresponds to a temperature of EW about130^0C, the protection is triggered, the temperature of the armature winding reaches a temperature of 155^0C. The scheme does not require installation in TEM because temperature sensors directly EW on the TEM is a sensor. This makes the protection of TEM is simple and reliable. In this structure as a real option divider for practical implementation can serve as chip 4-Quadrant Multiplier/Divider AD734 © Analog Devices, Inc. The scheme supports two modes of the analog division. It is recommended for use as an analog divider, which operates in the direct voltage regulation. This mode is more accurate, flexible and allows increasing the frequency of the chip. The second argument, which should be subject to control, is the speed of train. As you know, this option is strictly regulated by the Rules of safety in mines [11] differentiated by the technological parts of the underground route of movement of the locomotives. The most important safety factor is to limit the velocity of the ERC according to the condition of the allowable stopping distance for the carriage of goods should not exceed 40 m, and for the carriage of personnel 20 meters. Braking distance the ERC calculated in terms of the worst case - load downhill to the trunk. This phase is the most dangerous, the speed

limit on it up to 10 km/h, although (for traction) the train can reach a much higher speed.

In different time periods of development types of mine locomotives have been developed and are in operation until the present time, a line of speed controls locomotive including mining [5, 14].
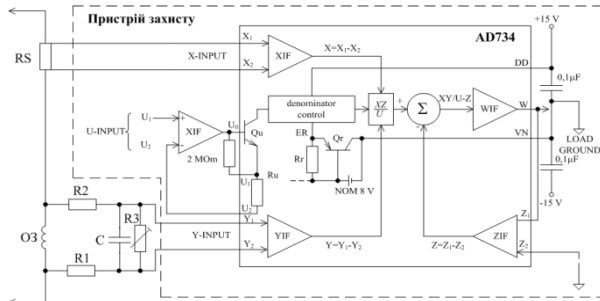

Figure 4. The protection circuit of the traction of the mining electric motor from overheating using chip AD734

Thus, in [5] the list of speed measuring devices installed at the mine electric locomotives type 10KR, 14KR production of the Alexander engineering plant (Russia) is presented. Double system in the first block, the sensor comprises a permanent magnet generator, generating a current whose value is proportional to the speed of rotation of the rotor. The second block magnetic tachometer that produces these currents and shows the speed of the locomotive on the remote control operator. The sensor is mounted on the gear cover traction transmission of the locomotive and connected to the gear reducer using your own gear. According to [14], for mine locomotives LG type manufactured by ASEA (Sweden) to control the speed of movement of the locomotives use two options. In the first sensors mounted on the gear shaft of the traction transmission, the second structurally inserted into TEM. Both methods have the same drawbacks as in the previous case.

To control the speed of movement of domestic transport currently used in a number of ways, based on a control of the rotational speed of the traction motor or wheelset with subsequent peterosborn in the speed of the train [5, 13]. However, if conditions electrolocation that operate on the ground, the variants of these systems of control in varying degrees are acceptable for the

conditions of their use underground achieve the necessary efficiency of such methods is problematic [10]. According to the authors, the reliability of the speed meter can be repeatedly increased by means of the method of sensorless control using only the electrical parameters TEM. It is known [14] that for TEM sequential excitation current and voltage uniquely determine the speed of rotation. In the general case, the rotational speed TEM is [14]:

$$\omega = \frac{U_я - IR_я}{C_\omega \Phi}, \qquad (4)$$

where $U_я$– the tension on the anchor; I – the current of TEM; $R_я$ – the resistance of the armature winding; Φ– magnetic flux; C_ω– constructive ratio.

In electric mode it is common to use linear speed

$$v = \frac{U_я - IR_я}{C_v \Phi}. \qquad (5)$$

As is known [14], for TEM series excitation magnetic flux is a function of current $\Phi = f(I)$, then the expression (5) would have the following form

$$v = \frac{U_я - IR_я}{C_v f(I)}. \qquad (6)$$

Despite the complex dependence of the magnetic flux from the current (due to saturation of steel) it can be expressed by a hyperbola with the exponent $x < 1$, that is $\Phi \approx I^x$. Then the expression (6) will be

$$v = \frac{U_я - IR_я}{kI^x}. \qquad (7)$$

Using real Electromechanical characterization of TED and setting a current value to determine the appropriate speed v and to calculate the value kI^x. Calculations show that for different characteristics of the exponent x is in the range $0,4 - 0,6$. If value is defined x, then the value of the coupling coefficient k is equal to

$$k = \frac{U_я - IR_я}{vI^x}. \qquad (8)$$

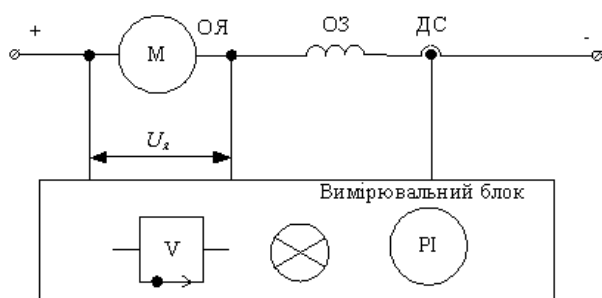The structure of the proposed speed meter shown in Fig. 5.

Figure 5. Speed meter structural diagram:
M, ОЯ – respectively, the armature and field winding of the traction electric motor; DC - the current sensor

The value of the armature voltage and current of the motors is applied to the input of the measuring unit that calculates the current speed of the locomotive and produces a value on a display device registration. In excess of the speed above the permitted value, the warning lamp lights up. In addition, the display and the memory device are output values of the motor current to inform the driver about the current load, as in the present tense, and if you want to play in the future.

Conclusions. The quality indicators of functioning devices, temperature monitoring and speed measuring devices, which are used in traction electromechanical systems with TEM DC series excitation modern mine electric locomotives are analyzed and evaluated. The main reasons for their low reliability are founded and the direction of improvement - sensorless control methods is simultaneously determined. The results of the studies suggested the functional and structural schemes of the probes that are recommended for implementation.

References

1. Shidlovskiy A.K., Pivnyak G.G., Rogoza M.V. and Vipanasenko S.I. Geoekonomika ta geopolitika Ukraini [Geoeconomics and geopolitics of Ukraine], Dnepropetrovsk: *Natsionalniy girnichiy universitet Publ.,*(2007.

2. Babec E.K., Shtanko L.A. and Salganik V.A. Sbornik tehniko-ekonomicheskih pokazateley gornodobiyayuschih predpriyatiy Ukrainyi v 2009–2010. Analiz mirovoy konyukturyi ryinka ZhRS 2004–2011 gg [Compilation technical and economic parameters of mining enterprises of Ukraine in 2009-2010 years. Analysis of the global IO market conditions 2004-2011], Kryvyi Rih, *Publishing House Publ.* 2011.

3. Noskov V.I., Lipchanskiy M.V., Blindag V.I. (2011). Kontrol i diagnostika motor-vagonnyih poezdov s ispolzovaniem neyronnyih setey [Monitoring and diagnostics motor-car trains using neural networks]. *Utilities city. KNAMG Publ*, **101**, 278–283.

4. Li Yu, Zhang Yu, Zhang T. (2014) Simulation and experimental studies of speed sensorless control of permanent magnet synchronous motors for mine electric locomotive drive, *International Journal of Control and Automation Publ.*,**7**(1), 55-68.

5. Sinchuk O.N., Guzov Je.S., Fedotov V.A., Chernaja V.O. (2014). Ustrojstvo dlja kontrolja i zashhity ot peregreva tjagovyh elektrodvigatelej shahtnyh elektrovozov [Device for control and protection from overheating traction motors mine electric locomotives], *Elektrotehnicheskie i kompjuternye sistemy Publ.* **15**(91), 278–283.

6. Zagirnyak M., Romashykhina Zh., Kalinov A. (2013). Improved reliability of diagnostics of induction motor broken rotor bars, *Proceedings of the XVI International Symposium on Electromagnetic Fields in Mechatronics, Electrical and Electronics Engineering*, Ohrid, Macedonia, 2 – 14th September.

7. Shavkun V.M. (2014). Diagnostuvannya tyagovih elektrichnih mashin elektrotransportu [Diagnosis of traction electric machines electric], *Vostochno–Evropeiskii Zhurnal Peredovykh Tekhnologii Publ.,* **17**(67), 48 – 52.

8. Sinchuk O.N., Guzov Je.S., Sinchuk I.O., Kalmus D.O., Chernaja V.O. (2014). Voprosy povyshenija nadezhnosti sistemy monitoringa temperaturnyh rezhimov tjagovyh elektricheskih dvigatelej rudnichnyh elektrovozov [The issues of reliability monitoring system temperature regimes traction electric motors mine electric locomotives]., *Visnik KrNU imeni Mihajla Ostrograds'kogo Publ,* **4**(87), 44 – 50.

9. Sinchuk O.N., Guzov Je.S., Sinchuk I.O., Debelyj V.L., Debelyj L.L. (2014). O bezdatchikovom sposobe kontrolja skorosti dvizhenija rudnichnyh jelektrovozosostavov [About the sensorless control method speed mine electromotostiv], *Vostochno–Evropeiskii Zhurnal Peredovykh Tekhnologii Publ.* **4/9**(70), 59 – 63.

10. Chernaya V.O. (2013). K voprosu analiza povrezhdeniy tyagovyih dvigateley shahtnyih elektrovozov [On the analysis of damage to electric traction motor shaft], *First Ukrainian scientifically conference of students and young scientists*. Dnipropetrovsk, Ukraine, 421–422.

11. NPAOP 10.0 – 1.01 – 05. Pravila bezpeki u vugIlnih shahtah [Your safety in mines. 10.0–1.01–05], Lugansk, Ukraine, *Kopicentr Publ.*, 2005.

12. Bertil Oberg. Computer-controller ore transformation at the LKAB mine in Kiruna, *Sweden Information of ASEA*, 1979.

13. Butt Yu.F., Gryaduschiy V.B., Debelyj V.L., Koval A.N., Furman A.L. (2009). Shahtnyiy podzemnyiy transport: spravochnoe izdanie. Shahtnyiy lokomotivnyiy i relsovyiy transport [Mine underground transport: reference book. Mine locomotive and rail transport], Donetsk, Ukraine , *VIK Publ.* **1**, 481 p.

14. Rozenfeld V.E., Isaev I.I., Sidorov N.K., Ozerov M.S. Teoriya elektricheskoy tyagi [Theory of electric traction], Moscow, Russia, *Transport Publ.*,1995.

THE FORMING OF THE ADAPTIVE PROCESS CONTROL OF IRON ORE DEGRADATION IN CONDITIONS OF CHARACTERISTICS UNCERTAINTY

Tron V. V., PhD, Associate prof., Maevsky K.V., M.d student,

Kryvyi Rih National University

Abstract. The article presents the results of the analysis of the methods of the automatic control of the technological process of iron ore disintegration in conditions of iron-ore raw material characteristics and technological process parameters uncertainty. The articles and works about the principles of mill control and the methods of the shredding analysis were analyzed. The analysis the library of adaptive controllers is represented. The model of the ball mill was created in the simulation environment MATLAB / Simulink. In this work are represented the principles of using the PID controller, the work of adaptive controllers based on the Ziegler-Nichols methods. The results of using the adaptive controllers based on differential filtering component with usage of Tastin approximation (Ziegler-Nichols controller with D-component filtration) and the methods of rectangular and trapezoidal discrete sampling are represented. The results of the simulation show that the adaptive Ziegler-Nichols controller for the 3-order processes based on differential filtering component with usage of Tastin approximation is the most efficient controller for the control of the grinding process of the various types of iron-ore raw material. Comparing to the classical PID-controller it provides the smaller measure of inaccuracy, which is 0.01%-0.81%. This controller provides the following results: overshoot - 16.7, the installation of the transition process - 69.5 seconds.

Keywords: automation, adaptive control, ore degradation, PID controller.

Introduction. Degradation is the most power-consuming process among the technological processes of the ore-dressing plant. During this process the ore is constantly disintegrating to the required size (-0,074mm, -0,05mm, 0,045mm) according to the stage of ore degradation. The first stage of degradation is determinative in the matter of the following quality of the product; therefore, the increase of effectiveness of the automatic control and the updating of the equipment (the mill, the power modules, the piping) is the main task for the quality assurance and the reduction of the prime costs of the concentrate [1]. As a general criterion of efficiency of grinding ore typically use quantity of material required class size in the shower classifier that works in closed loop with the mill. This figure depends on a number of factors which are constantly changing, in particular, the characteristics of raw materials, operational management settings.

The ball mill requires the efficient and adjusted algorithm of raw material filling, which grants the efficient use of the input raw material and the mill itself [2]. One way to increase the effectiveness of degradation is usage of the adaptive control methods. Adaptive control systems adapt regulatory controls to the changes in the system parameters and control the object taking into the account the new conditions and changes of such parameters as for example variability characteristics of iron ore, that is supplied to the ball mill for grinding [3]. The operating experience with adaptive systems shows the efficiency of their implementation in the technological processes in mining factories, that permits to improve the accuracy and stability of the control systems and, as a result, to improve the quality factors of the technological processes of iron-ore degradation [4-8].

Materials and Methods. The methods of the operational control of the raw material quality on the different stages of its processing are highlighted in the works [9, 10]. During the process of raw material mining the heterogeneous ore is formed, that leads to the instability of the mineral raw materials, which is sent for the following dressing [11, 4 ,7-8]. The process of control with due regard for the efficient energy use, ecological safety and economical production of the ore-dressing plant is represented in the work [4-8, 12-14].

For effective work of ball mills must comply with certain correlation between the size of bullets and pieces of ore, loaded to the working capacity of the mill [13, 14]. For ball mill control action is the performance by the original ore, water consumption. The change in the raw material

properties (hardness, breakage, particle-size analysis), sand consumption, the state of the objects, fetting can be an energizing influence. Operated variables grinding process: slurry density, the structure of the finished material (class %–0,074mm), efficiency according to the class in the waste hole of the mill, engine power [14-15]. In the article [4] the technological process of the magnetite quartzite dressing is proposed to be considered as a many-dimensional discrete system in matrix-vector form. To determine the technological processes (TP) of dressing as multiply nonlinear dynamic objects it was suggested to use the multidimensional analogues of neural predictors: NNARX, NNARXMAX, NNOE. The inverse dynamic models are used for the automatic control of the local processes, mainly ones with the schemes of the circuit type SISO (single input - single output).

The difference ADL (p, q) models structures are the base of the method of synthesis of the adaptive ARMA-process control systems [6]. The adaptive properties of such models are derived due to the usage of the designed method of neuromorphic control of weight numbers γ_0, γ_1, γ_2,..., γ_n in the discrete adaptive structure ARMABiS, which was developed on the basis of the output coordinate reference value $y^*(t)$ determination in the discrete MA(q)-model with the distributed lag order (0, q).

The article [8] proposes the hybrid mathematical model of the iron-ore degradation closed loop; its analytical part describes the ore-flows and the changes of the grain size distribution of the iron-ore in the technological units. The fuzzy Takagi-Sugeno rules are used for the forming of the functions of division and fragmentation. It is noted, that the main task of the control of the mineral processing equipment, for example, the hydrocyclones, is to provide such mode of operation that guaranties the particle-size distribution, which is necessary for the efficient derivation of the impregnations.

Thus, the usage of the adaptive systems with complex operation algorithms in the control processes of iron-ore reprocessing is provided by the high level of the development of modern computer equipment. However, this approach does not exclude the difficulties of providing the reasonably qualitative control of the efficiency indexes of the technological processes and the necessity of the system stability assurance during the change of parameters. Therefore, it is appropriate to review the methods of adaptive control that uses the on-line data about the internal state of an object and a priori information about the patterns of grinding along with classical methods of regulation.

The analysis of the adaptive controllers while controlling the ball mill simulation model. The analysis of the controller in the conditions of parametric and coordinate disturbances.

Results. The ball mill automatic control system (ACS) works on principle of the difference between the desired value and the actual outgoing value. The mathematic model of the iron ore degradation was taken as an object and presented in the article [14].
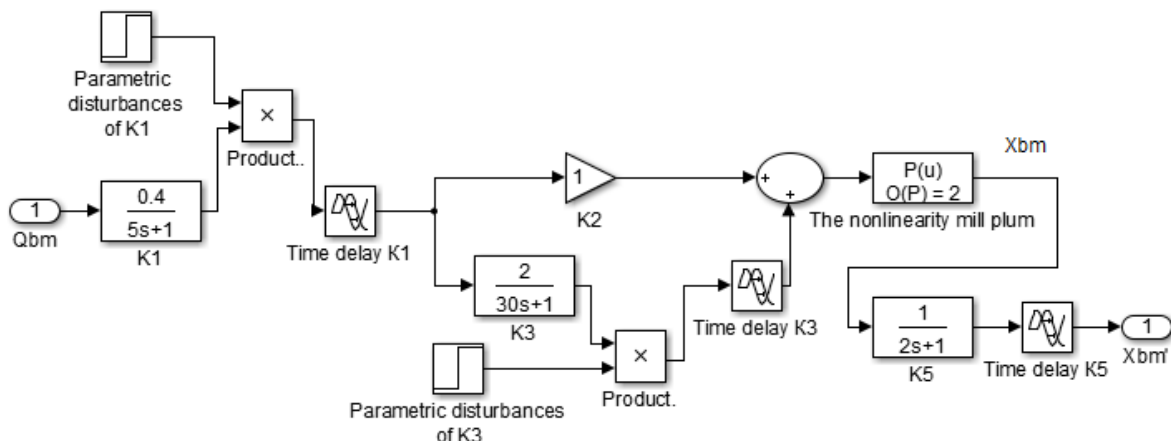

Figure 1. The object model of ball mill in Simulink

The relation between the output of the required class of coarseness and the ore consumption is nonlinear. The designations on the scheme: Qbm – is the mass flow rate, Xbm – is the quantity of the 0.074 mm class in the ground ore (fig.1). As a definition we use the quantity of the required class in the slurry of the waste hole. One of the ways of the ball mill control in the factories of ore dressing is using the proportional-integral-derivative (PID) controllers.
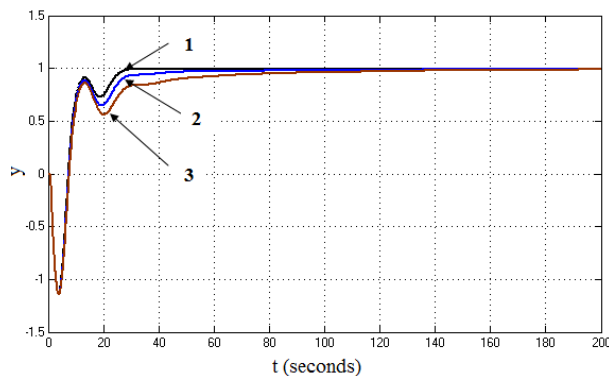

Figure 2. The control of the ACS degradation process with the change of the coefficients K1 and K3: 1 – minimum value, 2 – medium value, 3 – maximum value

Fig. 2 represents the state of the transient process of the iron ore degradation using the PID controller in the control loop in the conditions of parametric and coordinate disturbances. The parametric disturbances are shown as the change of the coefficient in the transfer functions K1and K3. The values changed within the limits mentioned in the work [14].

In cases when the values of K1 and K3 are close to the maximum the work of PID controller is more efficient. Under the influence of the parametric disturbances the system is out of balance. The simulation of the random changes of the coefficients within the certain limits (±10%), namely the changes of «K1» and «K3» of the transfer functions are represented on the fig.1 in the boxes "Parametric disturbances of K1" and "Parametric disturbances of K3".

The analysis of the PID controller (fig.3) shows the necessity of using the adaptive controller in the control loop. It would be able to evaluate the changeable values and correct the

parameters of the controller during its work to provide the stable and efficient control under all possible modes. Therefore, we'll review the ACS (automatic systems control) with several adaptive controllers [16].
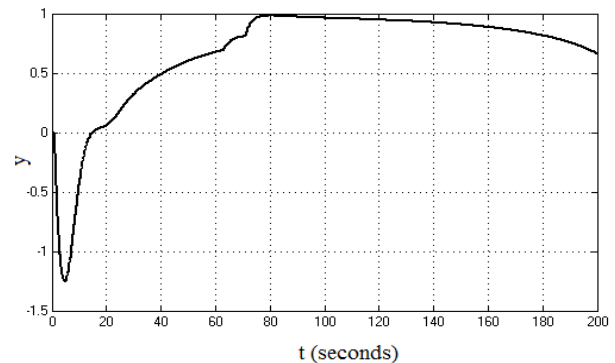

Figure 3. The transient process with the random change of the K1 and K3 coefficients

The mathematical description of the controller is represented in the following form.

Ziegler-Nichols controller for third order processes with filtration of derivative-component using Tustin approximation (ZN3FD). Control law

$$u_k = q_0 e_k + q_1 e_{k-1} + q_2 e_{k-2} - p_1 u_{k-1} - p_2 u_{k-2,}$$

where e_k - control error ($e_k = w_k - y_k$). Controller parameters are calculated using following equations [16]

$$q_0 = K_p \frac{1 + 2(c_f + c_d) + \frac{c_i}{2}(1 + 2c_f)}{1 + 2c_f}$$

$$q_1 = K_p \frac{\frac{\tilde{n}_i}{2} \quad 4(c_f + c_d)}{1 + 2c_f}; \qquad (1)$$

$$q_2 = K_p \frac{c_f(2 - \tilde{n}_3) + 2c_d + \frac{c_i}{2} - 1}{1 + 2c_f};$$

$$p_1 = \frac{4c_f}{1 + 2c_f}; p_2 = \frac{2c_f}{1 + 2c_f} \frac{1}{};$$

$$\tilde{n}_f = \frac{T_f}{T_0}; c_i = \frac{T_0}{T_i}; \qquad (2)$$

$$c_d = \frac{T_D}{T_0}$$

$$T_f = \frac{T_D}{\alpha}; Kp = 0.6Kpu; T_I = 0.5Tu; T_D = 0.125Tu, \quad (3)$$

where K_{Pu}- ultimate gain, T_u- ultimate period respectively, T_0- period of surveys controller, T_D – time constant of differentiation, T_I – time constant of integration, $\propto$ - filtration coefficient (where

usually $3 < \propto < 20$). The coefficients c_f, c_i, c_d – enter for easy image formulas [16].

Ziegler-Nichols PID controller for processes of second order (ZN2FR). Controller is based on forward rectangular method of discretization. Control law [16]

$$u_k = K_p \left[e_k - e_{k-1} + \frac{T_0}{T_I} e_{k-1} + \frac{T_D}{T_0} \left(e_k - 2e_{k-1} + e_{k-1} \right) \right] + u_{k-1}, (4)$$

where e_k - control error ($e_k = w_k - y_k$). This form of control law can be transformed to feedback form

$$u_k = q_0 e_k + q_1 e_{k-1} + q_2 e_{k-2} + u_{k-1}. \quad (5)$$

Controller parameters are calculated using following equations

$$q_0 = K_p \ (1 + \frac{T_D}{T_0});$$

$$q_1 = -K_p \left(\ 1 - \frac{T_0}{T_I} + 2\frac{T_D}{T_0} \right); \quad (6)$$

$$q_2 = K_p \frac{T_D}{T_0};$$

$$\mathrm{Kp} = 0.6 \mathrm{K_{P}u}; \mathrm{T_I} = 0.5 \mathrm{Tu}; \mathrm{T_D} = 0.125 \mathrm{Tu}, \quad (7)$$

where K_{Pu}- ultimate gain, T_u- ultimate period respectively, T_0- period of surveys controller, T_D – time constant of differentiation, T_I – time constant of integration [16].

Ziegler-Nichols PI controller for processes of second order. Controller is based on trapezoidal method of discretization (ZN2PI). Control law [16]

$$u_k = K_p \left[e_k - e_{k-1} + \frac{T_0}{T_I} * \frac{e_k - e_{k-1}}{2} \right] + u_{k-1}, (8)$$

where e_k - control error ($e_k = w_k - y_k$). This form of control law can be transformed to feedback form

$$u_k = q_0 e_k + q_1 e_{k-1} + u_{k-1}. \quad (9)$$

Controller parameters are calculated using following equations

$$q_0 = K_p \left[1 + \frac{T_0}{2T_I} \right] ; q_1 = \ K_p \left[1 - \frac{T_0}{2T_I} \right], (10)$$

$$\mathrm{Kp} = 0.6 \mathrm{K_{P}u}; \mathrm{T_I} = 0.5 \mathrm{Tu}$$

where K_{Pu} - ultimate gain, T_u- ultimate period respectively, T_0 - period of surveys controller, T_I – time constant of integration [16].

All mentioned transient processes of adaptive controllers are represented on one diagram and shown on the fig.4.
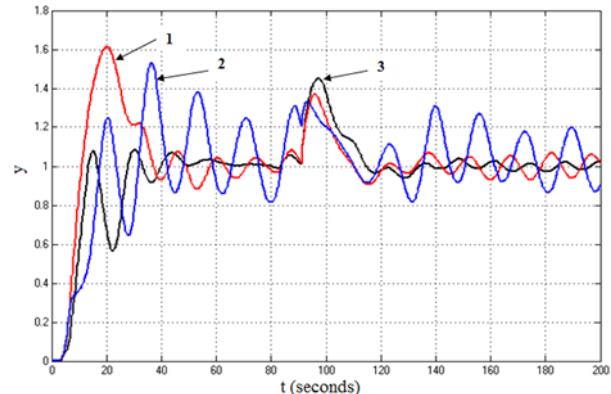

Figure 4. The example of the work of the controller with the changing of the system parameters during the functioning: 1-ZN3FD, 2 – ZN2FR, 3 – ZN2PI

Ziegler-Nichols controllers for the third-order processes with the D-component filtration and using Tustin approximation, Ziegler-Nichols PID controller for processes of second order (controller is based on forward rectangular method of discretization), Ziegler-Nichols PI controller for processes of second order (controller is based on trapezoidal method of discretization) were used to control the process of the degradation of ore raw material technological variations in the ball mill. The demonstrative results of the modelling are shown in the table 1.

Table 1. The comparison of control quality indexes using the adaptive controllers

Type controller	Values of the coefficients	t transient processes	б overshoot	h set value
1	2	3	4	5
ZN3FD	K1-0.35 K3-1;	69.5	16.7	1.004
ZN3FD	K1-0.35; K3-2;	91.1	29.8	1.005
ZN2FR	K1-0.35; K3-1;	85	53.7	1.006
ZN2FR	K1-0.35; K3-2;	146	70.4	1.006
ZN2PI	K1-0.35; K3-1;	66.9	48.4	0.9966
ZN2PI	K1-0.4; K3-1;	51.8	74.1	0.8872

After the number of researches we have defined that Ziegler-Nichols adaptive controller is most appropriate controller for the ball mill filling automatic control system for the third stage processes with D-component filtration and using Tustin approximation. This controller provides the following results: the overshoot – 16.7, the period for transient process installation – 69.5 seconds (fig.5).
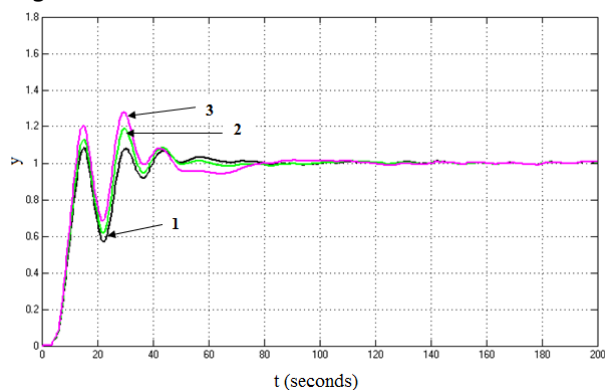

Figure 5. The transient process of Ziegler-Nichols controller for the third-order processes with the D-component filtration and using Tustin approximation with various values of K1 and K3: 1 – minimum value, 2 – medium value, 3 – maximum value

Therefore the using of this controller is well-taken in the view of better quality of the required class in the waste holeof the mill.

Conclusions. The Ziegler - Nichols controller for the third - order processes with the D-component filtration and using Tustin approximation is the most appropriate controller for mill control. In the presence of the required class in the waste hole it increases the work of the mill by 0.01%-0.81%, which is better than the classical PID controller. The improvement of the control processes of the iron-ore degradation with due regard for the multidimensionality of the real objects is the main course of the further investigations. The further analysis is dedicated to the construction of the multi-channel systems of adaptive control of the technological processes of the iron-ore degradation in the conditions of mining factories.

References

1. Andreev S.E., Perov V.A., Zverevich V.V. Crushing, grinding and screen separation of the mineral resources. 3th ed. Moscow: Nedra, 1980.

2. Morkun V., Tron V. (2014). Automation of iron ore raw materials beneficiation with the operational recognition of its varieties in process streams. *Metallurgical and Mining Industry*, **6**, 4-7.

3. Pivnyak G.G., Vaysberg L.A., Kirichenko V.I., Pilov P.I., Kirichenko V.V. Grinding. Energy and technology. Moscow: Ruda i mettalyi, 2007.

4. Kupin A.I. Intellectual adaptive control of the stages of the magnetite quartzites dressing technological process under uncertainty. PhD diss., Kryvyi Rih National University, 2009.

5. Xiaoling Huang. Production Process Management System for Production Indices Optimization of Mineral Processing / Xiaoling Huang, Yangang Chu, Yi Hu, Tianyou Chai, IFAC, Research Center of Automation, Northeastern University, Shenyang, P.R.China 110004.,2005.

6. Shchokin V.P. Adaptive control of the agglomerative structure based on the autoregressive models with normalization. PhD diss., Kryvyi Rih National University, 2012.

7. Morkun N.V. System of the adaptive control of the iron-ore magnetic separation processes based on the methods of the ultrasonic control. PhD diss., Kryvyi Rih National University, 2005.

8. Podgorodetskiy N.S. Energy efficient adaptive control of the closed cycle of the ore dressing based on the hybrid model with fuzzy logic. PhD diss., Kryvyi Rih National University, 2011.

9. Morkun V. S., Morkun N. V, Pikilnyak A.V. (2014). Ultrasonic facilities for the ground materials characteristics. *Metallurgical and mining industry*, **2**, 31-35.

10. Morkun V., Morkun N., Pikilnyak A. (2015). The study of volume ultrasonic waves propagation in the gas-containing iron ore pulp. *Ultrasonics*, **56C**, 340-343.

11. Morkun V., Tron V. (2014), Ecological and economic optimization of iron ore processing automated control. *Metallurgical and Mining Industry*, **5**, 8-11.

12. Morkun V., Tron V. (2014). Ore preparation multi-criteria energy-efficient automated control with considering the ecological and economic factors. *Metallurgical and Mining Industry*, **5,** 4-7.

13. Linch A.D. Cycles of the crushing and grinding: modelling, optimization, engineering and control. Moscow: Nedra, 1981.

14. Nesterov G.S. Technological optimization of the separating plants. Moscow: Nedra, 1976.

15. Maryuta A.N., Kachan Yu.G., Bunko V.A. Automatic control of the technological processes of the separating plants. Moscow: Nedra, 1983.

16. Self-Tuning Controllers Simulink Library. 2015. Available at: http://www.fai.utb.cz/people/chalupa/stctool/index.htm.

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USING NEURAL NETWORK TO CONTROL CUP-SHAPED PELLETIZER

Kuzmenko A. S., Senior lecturer, Baranovskaya M. L., PhD, Associated prof.

<u>*Kryvyi Rih National University*</u>

Abstract. Cup-shaped pelletizer is complex machine in terms of automatic control. A large number of incoming (humidity mixture, cup rotation speed, the angle of cup, mixture and water discharge into the cup), the outgoing (diameter, strength and moisture of pellet) parameters and external influences (air humidity and temperature, the content of iron in the mixture) dependent on each other non-linear and in some cases not explicitly, that creates great difficulties in controlling cup-shaped pelletizer. The definition of a suitable system of automatic control cup-shaped pelletizer series of papers, including this one. In this paper, justified the choice of direction to find a suitable control system. To do this, a mathematical model is made up of single-drive control pan rotation cup-shaped pelletizer. In the model for comparison of automatic control systems use the classic PID controller and a single-layer neural network trained by the algorithm "delta rule". Comparison of control systems for different incoming influences. The main parameters of transient processes (the first matching t_y, overshoot σ, time of transient process $t_{пп}$) and found error rates positioning c_0, c_1 speed and acceleration of c_2 for each type of control system. Showing laws, which are found appropriate error rates. For the visibility of the different control systems are graphs errors c_0, c_1 and c_2.

Keywords: neural network, control, cup-shaped pelletizer.

Introduction. In the production of pellets, pelletizing process is not energy-intensive. However, the quality of the pellets increases significantly the power consumption in the burning step. On the pelletizing process in cup-shaped pelletizer is influenced by many factors, including: the iron content in the mixture, the basicity of the mixture, size of the mixture, mixture flow into the cup, the angle of cup, cup rotation speed and humidity mixture. Timely response in the management cup-shaped pelletizer to reject parameters significantly improve the quality of raw pellets, which further lead to a reduction of energy consumption for the production of pellets as a whole [1,2].

Analysis of research and publications. With increasing demands on the quality of the finished product, management units without automated systems is not possible [9]. Effective control can be achieved by using multi-level automation systems with the use of computer technology — automated process control systems (PCS) [10]. In this direction, there are many scientific papers as research-all those technological process-pelletizing plants [3, 4, 5, 6, 11] and on the preparatory process raw material (additives) and formation (dosing) mixture for the production of raw and done pellets [7, 8, 13, 14].

Materials and methods. Determine the feasibility of using classical and hybrid neural networks for control cup-shaped pelletizer.

Presentation of the material and results. For the analysis of the control object in the theory of automatic control, common to use differential equations. They describe the properties of the system and allow evaluating behavior change input parameters.

There are two basic modes of operation of the automatic control:

- steady state of operation in which the components of the state vector of the system do not depend on the time of measurement;

- dynamic mode, in which the components of the state vector of the system are functions of time.

Steady and dynamic modes of the linear system can exist if the apply on the system signals that change over time. The difference is that in transition process effects or certain derivatives thereof include step changes. For some time after a step change in the value and its derivative, the system undergoes a transition process. After the end of the system is in steady state, until the effects of new or changes in the structure of the system.

One of the main requirements for management systems, is to provide the necessary accuracy in all operating modes. In the steady state

of the control system, the quality of its operation can be assessed according to the static characteristic of the system.

An important characteristic of the control system is the relation between the value of the control parameter and the value of external influence. By type of relationship between the value of the manipulated variable and external influences system is divided into static and astatic. System is called a static reference to external influence, if under the influence tends over time to reach a certain value, the error is also seeking to achieve sustainable value. Therefore, static automatic control system cannot provide managed persistence parameter at variable load.

The automatic control system is called static if the constant input exposure control error tends to zero regardless of the magnitude of the impact. If the concept of a static system is absolute, then the concept of astatic automatic control system is true only for a specific component of the vector of the initial state of the system. Astatic automatic control system characterized by different order astatism depending on the number of integrating links open loop.

One of the main requirements for the automatic control system cup-shaped pelletizer is to provide an accurate work in all modes. In steady-state operation, automatic control system quality of her work can be estimated from the static characteristic of the system and error rates [12]. For each monitored parameter works cup-shaped pelletizer can determine the error rate, Taylor of the transfer function of Fe(s) in error, which is caused by exposure to:

$$F_e(s) = \frac{E(s)}{X(s)} = F_e(0) + \frac{F_e'(s)|_{s=0}}{1!}s +$$

$$+\frac{F_e''(s)|_{s=0}}{2!}s^2 + \dots = c_0 + c_1 s + \frac{c_2}{2}s^2 + \dots \quad (1)$$

where: c_0 – error rate position; c_1 – error rate of speed; c_2 – error rate of acceleration.

Starting from (1) loop error behavior in time can be represented by a series [12]:

$$e(t) = c_0 x(t) + c_1 x'(t) + c_2 x''(t) / 2 + \dots \quad (2)$$

If we start from the expression (2), when a predetermined maximum error e_m control using the principle of equal effects coefficients are [12]:

– X_m – the maximum deviation of the reference signal for the control system cup-shaped pelletizer, which will ensure the required accuracy: $X_m < e_m/(3\ c_0)$;

– $max(dx/dt)$ – the maximum rate of change of the reference signal: $max(dx/dt) < e_m/(3\ c_1)$;

– $max(d^2x/dt^2)$ – the maximum acceleration signal: $max(d^2x/dt^2) < 2\ e_m/(3\ c_2)$.

Thus, the coefficients c_0, c_1 and c_2 determine the accuracy and speed of the system. Error values indicate the order astatizm system. In the case of a static system error c_0 will have a value different from zero. For a system with first order astatism error c_0 will be zero, and the errors of higher order will have non-zero values. The physical meaning of the error to your system the drive cup is as follows: c_0 - a mistake on the rotational speed of the cup, and c_1 - a mistake to accelerate the cup.

The model of control system for one control action, the speed of rotation the cup pelletizing, to find the coefficients c_0, c_1 and c_2 is shown in Figure 1.

Switch1 and Switch2 are responsible for the shape of the reference signal. At constant reference signal schedule transient speed is shown in Figure 2a. Indeed, with t tending to ∞ after the transient input signal $x(t) = 1$, and its derivatives, $x'(t) = 0$ i $x''(t) = 0$. Therefore, from (2) we have $e(t) = c_0$. For a given control signal coefficient c_0 is 0.

To determine the speed error c_1 we make the change of the input signal with a step (Step) on a linearly increasing (Ramp) according to the relation $x(t) = l_0(t)\cdot t$, where $l_0(t)$ – a single step Heaviside function. At the end of the transient process $x'(t) = 1$, $x''(t) = 0$, using (2), we get [12]:

$$e(t) = c_0\ l_0(t)\cdot t + c_1, \quad (3)$$

then

$$c_1 = e(t) - c_0\ l_0(t)\cdot t. \quad (4)$$

Determination of the coefficient errors to speed c_2 is arranged as follows: on the investigated automatic control system will provide a signal to the parabolic shape $x(t) = l_0(t)\cdot t^2/2$. At the end of

the transient process will be derived the following values: $x'(t) = t$, $x''(t) = 1$, and the higher derivatives of degree k for all $k > 2$, will be zero $x^{(k)}(t) = 0$. Thus, in steady state expression (2) for error becomes:

$$e(t) = c_0 t^2/2 + c_1 l_0(t) \cdot t + c_2/2 + \dots . \quad (5)$$

From this [13] we find c_2:

$$c_2 = 2(e(t) - c_0 t^2/2 - c_1 l_0(t) t) \quad (6)$$

To find the error factor c_1 and c_2 in our scheme is necessary to switch the reference signal respectively Switch1 to position II and Switch23 to position 1. The value of the error factor $c_1 = 0.084$, and $c_2 = 0.0236$, as shown by the corresponding graphs in Figure 2b and Figure 2c. Analyzing transients describe their main parameters: the first matching $t_y = 0{,}133$s overshoot $\sigma = 55{,}7\%$ and time of transient process $t_{nn} = 2$ s.
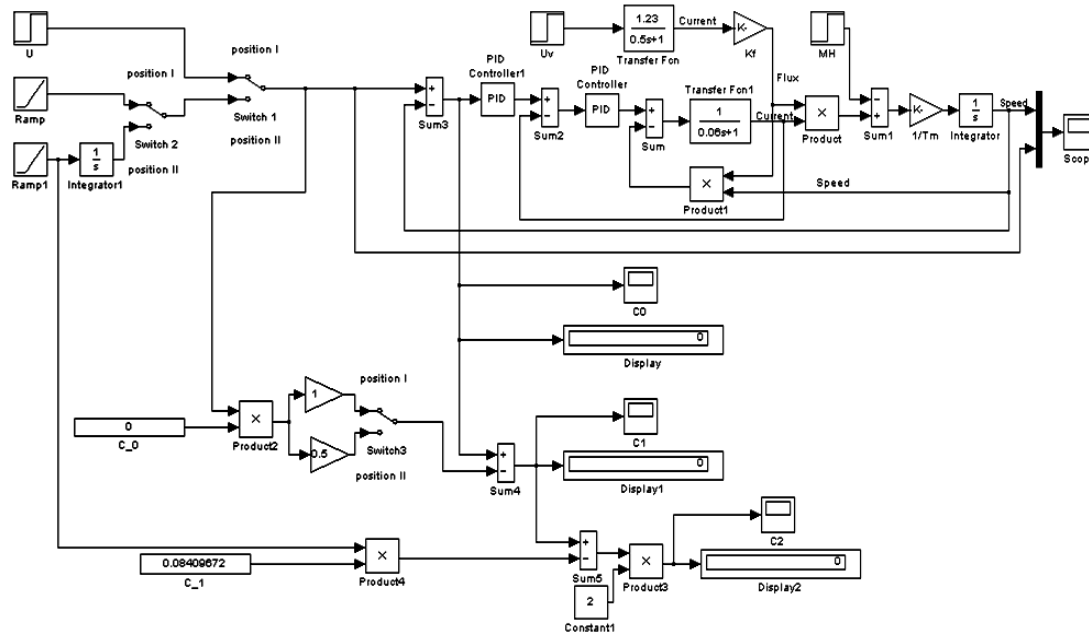

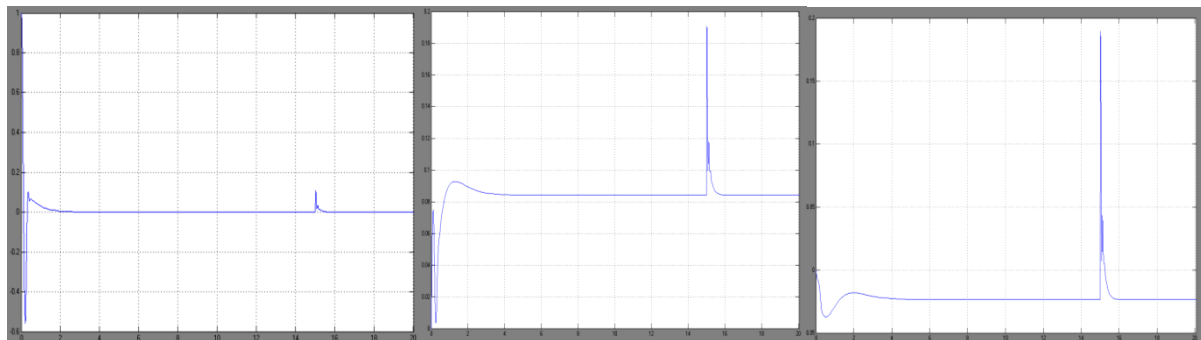**Figure 1**. A model for finding the coefficients c0, c1 and c2 using classical PID controllers

Figure 2. Transient processes for error c0, c1 and c2 in the management of the cup speed using PID controllers

In reviewing the operation of the system control on one channel - cup rotation velocity in the model system instead of PID will attend a classical neural network trained by the simple algorithm - delta rule. Leave unchanged model of the electric rotating the cup of pelletizer for comparative analysis to determine the accuracy of its work and compare the results obtained previously.

The results of the simulation are as follows:

positioning error rate takes the value $c_0 = 1{,}69e{-}6$, which is comparable to modeling errors, so it can be considered equal to zero (Figure 3a); speed error rate $c_1 = 0.1$ (Figure 3b); accelerate error rate $c_2 = 0.1621$ (Figure 3c).

Transition process for a control system based on neural network characterized by the following parameters: the first matching $t_y = 0{,}125$ s, overshoot $\sigma = 21\%$ and time of transient process $t_{tp} = 2$ s.

Thus, the control system error rates characterized by its accuracy and speed in any type of signal, which allows to determine the dynamic

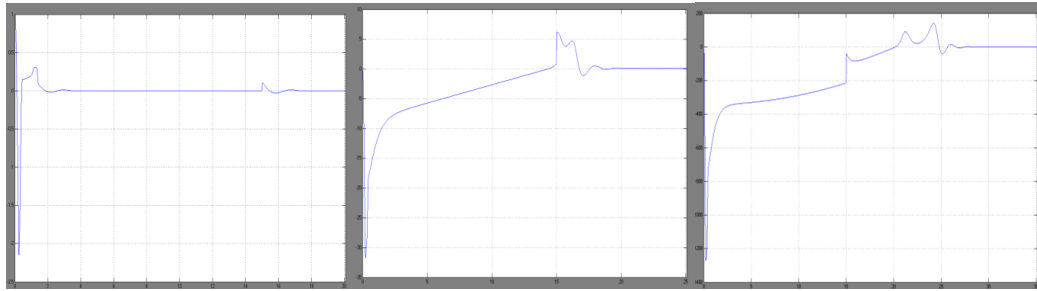error control and use them for teaching network in real time.

Figure 3. Transient processes for error c_0, c_1 and c_2 in the management of speed the cup with neural networks

Conclusions and future research. Analyzing the work of the two considered control systems using different regulators on the errors values, it is clear that better quality control system works using a neural network. Quality transients also better in the second variant.

Convenient determination of the error coefficients c_0, c_1 and c_2 in real time makes them suitable for online learning neural network.

Further research will be directed at providing a method of neural network training based on error rates c_0, c_1 and c_2.

Comparison of control quality with the use of different learning algorithms makes it possible to determine the best configuration of the neural network and learning algorithm.

References

1. Shchokin V.P., Kuz'menko A.I. (2013). Zasoby pidvyshchennya efektyvnosti roboty chashevoho ohrudkuvacha [Means of increasing the efficiency of cup pelletizer], *Journal of Kryvyi Rih National University*, **34**, 53-56.

2. Taravskiy M.F., Shumilov K.A., Trukhin G.M., etc. (1997). Issledovaniye protsessa okomkovaniya zhelezorudnoy shikhty i razrabotka algoritma yego upravleniya v avtomaticheskom rezhime [Investigation process okomkovanyya zhelezorudnoy shyhtы and ego development algorithm of automatic management in Standby. *Automation of production processes*, **2**, 58 - 65.

3. Fedorov N.V Avtomaticheskoye upravleniye tekhnologicheskimi protsessami okomkovaniya sypuchikh materialov [Automatic control of technological processes pelletizing bulk materials], Kyiv: Tehnika, 1976.

4. Dementieva Ye. M. Metod i etapy postroyeniya matematicheskogo opisaniya tekhnologicheskikh protsessov pro-izvodstva okatyshey pri razrabotke ASU TP fabriki okomkovaniya. Nauchnyye osnovy postroyeniya ASU TP okuskovaniya sypuchikh materialov [The method and the stages of construction of the mathematical description of technological processes of pro-production of pellets in the development of factory automation systems pelletizing. Scientific bases of construction of automated process control system agglomeration of bulk materials], Kyiv: Naukova dumka, 1980.

5. Bogayenko I.N., Burlyay I.YU., Grabovskiy G.G., Ryumshin N.A., Taravskiy M.F., Shumilov K.A. Razra-botka i proyektirovaniye ASU TP fabrik okomkovaniya gorno-obogatitelnykh kombinatov [The gap-processing and design automation systems pelletizing plant mining and processing], Kyiv: NVK "KIA", 2002.

6. Fedorovskiy N.V. Printsip postroyeniya ASU TP na aglomeratsionnykh i okomkovatelnykh fabrikakh. Problemy avtomatizatsii protsessov okuskovaniya sypuchikh materialov [The principle of construction of automated process control system at the sinter and pelletizing plants. Problems of automation of processes of agglomeration of bulk materials], Moscow: TSNIITEIpriborostroyeniya, 1985.

7. Zhuravlev F.M., Malysheva T.YA. Okatyshi iz kontsentratov zhelezistykh kvartsitov [Pellets from concentrates ferruginous quartzite], Moscow: Metallurgiya, 1991

8. Ignatov N.V., Sulimenko Ye.I., Ivashchenko V.P. etc. (2001). Perspektiva proizvodstva okuskovannogo metallur-gicheskogo syrya gorno-metallurgicheskogo kompleksa "Krivorozhstal'' [The prospect of the production of agglomerates of metallurgical raw materials mining and metallurgical complex "Kryvorizhstal"], *Teoriya i praktika metallurgii*, **4,** 10 - 13.

9. Tischner G, Uhlig I. (1999). Steuerung von Ghargen prozessen, *ATP 41*, **4**, 20-29.

10. Uhlig R., Bruns M. Automatisierung von Chargenprozessen, R. Oldenbourg Verlag, 1995.

11. Peter B., Oliver B., Gerhard K., Michael S. (2000). Modellgestützte Processfiihrung Chem, *Ing.-Teclin.-72*, **4**, 48-49.

12. Fedosov B.T. Obotsenke kachestva lineynykh SAR s ispolzovaniyem programm modelirovaniya. Avsilable at: http://model.exponenta.ru/bt/bt_0004.html

13. Shchokin V. Tkachuk V. (2014). Automatization of agglomerative production on the base of application of Neuro - Fuzzy controlling systems of the bottom level, *Metallurgical and Mining Industry*, **6**. 32–39.

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AUTOMATED DISTRIBUTED SYSTEM FOR UTILIZATION OF LOW-TEMPERATURE ENERGY OF MINE WATER AND VENTILATION AIR ON THE BASIS OF THE TECHNOLOGY OF HEAT PUMPS

Morkun V., Sc.D, Professor, Savytskyi O., PhD, Associate prof. Ruban S., PhD, Associate prof.

<u>*Kryvyi Rih National University*</u>

Abstract. The energy crisis and the need to reduce greenhouse gas emissions require research in the practical development of energy systems based on alternative energy sources. The article discusses the possibility of using heat pumps for heat utilization of mine water and ventilation air. Application of the large number of pumps requires automatic control of the operation parameters in order to optimize the whole system.Control issues of an individual heat pump were well reviewed by researchers in many sources. At the same time there are much less works devoted to analysis of the operation issues and control regimes of groups of heat pumps. And very small number of works is devoted to the questions of supervisory control of groups of heat pumps, which consist of heat pumps "water - water" and "air - water".The aim of the study is to validate the feasibility of using heat pumps for heat utilization of mine waters and ventilation air, and development of algorithms for supervisory control of distributed system for utilization of heat from these sources, as well as formation of optimum modes of teamwork of heat pumps, both on the surface and in the deep horizons of the mine.

In the article the classical methods of analysis parameters of the particular system at one of the mines of Kryvyi Rih Basin and methods of the modern theory of automatic supervisory control of distributed systems were used. The processes visualization techniques considering a human perception and decision-making had also been applied when creating the human-machine interface of automated distributed system for utilization of low-temperature energy of mine water and ventilation air.

Keywords. Non-conventional sources of energy, mine water, ventilation air, heat pump, microclimate in the mine, automated distributed system, SCADA.

Introduction. Nowadays much attention is paid to sources of the low-potential heat energy (LPHE). A total of more than 6,7 million heat pump units were installed since 1994 [1]. This amounts to an installed thermal capacity of nearly 224 GW. All installed heat pumps produce 120,8 TW·h of useful energy, 77,8 TW·h of which being renewable. Their use saved 99,1 TW·h of final and 47,1 TW·h of primary energy [1].

In this regard, in recent years a large number of studies and analytical materials have been published, which highlight heat pumping solutions and their potential for household and industrial usage [2–8].

One promising direction of heat pumps application is the using of low-temperature renewable energy sources of mines [9, 10]. The use of mine water for space heating or cooling purposes has been demonstrated to be feasible and economic in applications in Scotland, Canada, Norway, and the USA [11].

In mines the sources of low-potential heat energy (LPHE) areas are follows:

- a fan with the capacity of 500 m^3/sec produces $3.8\cdot10^8$ kJ of heat annually.

- mine drainage with the flow rate of 150 m^3/h produces up to $2.9\cdot10^9$ kJ heat annually.

Compressor stations, high power electric drives of hoisting facilities are also sources of LPHE.

Mines annually release this tremendous amount of heat into the atmosphere or water in the form of mine water and ventilation air. With a heat pump we can reuse this heat for heating, production of hot water/steam for industrial processes and so on. Also there are options of converting heat into the cold. Users, which are situated near the mines, can use active ventilation and air-to-water heat exchangers for obtaining a huge number of low potential heat.

Distributed systems of thermal power generation based on heat pumps require coordination of the work due to changing the flow of mine water as a source of low-potential heat energy. In addition the heat consumption (and consumption of cooling in summer) of buildings is changing, as well as consumption of hot water depending on the work of showers in domestic housing of mine. At the same time in order to avoid overspending of power it is necessary to control the amount of operating pumps and the heat output in the range 75-100% of nominal.This

led to the use of SCADA system for monitoring and control of operating modes of separate heat pumps on the common system of hot water and heat supply in the cold season and cooling systems in the warm season.

Materials and Methods. The annual volume of water with the constant year-round temperature of 14-17 °C pumped out of 12 Kryvyi Rih mines is assessed to be about 12 mln m^3, its energy potential being 200 mln kWh per year. Along with the energy potential of mine ventilation air added this figure will double and can be compared with the potential of 3% of annual oil production by the PJSC Ukrnafta. These figures can be considered true if the whole potential of LPHE is used, but this is not always possible, e.g. due to lack of heat pipelines or because of the general tendency to decentralized power supply of housing objects.

Heat pumps that use low potential heat of mine waters and mine ventilation air will allow modernization of the municipal (centralized) heating of Kryvyi Rih and significant reduction of gas consumption. Then, some payback periodit is possible to greatly cut heating rates.

The feasibility study of the initial project that can be implemented in Kryvyi Rih is presented to demonstrate the above said.

In the city with the population of 655,000 people centralized heating boiler stations produce over 4200 thousand Gcal a year.

The suggested pilot project can provide heat for a mine and partly for one of Kryvyi Rih wards and produce 58008,5583 Gcal annually that makes nearly 1,4% of heat consumption of the city.

On average, when using the whole potential of low-temperature sources, it is possible to install heat pumps with total power of 13000 kW each of 12 mines of Kryvyi Rih .Half of this power can be used for mine's own needs, and the other half can go to the city's heating system. The total amount of heat from the 12 mines makes nearly 15% of the city's heat consumption. But, as heat pipeline systems of some mines are not connected with the city's heating system, it will be necessary to invest into pipeline building.

Before selecting a heat pump, it is necessary to calculate the minimum heat power necessary for certain premises and determine the possibleheat power from mine waters and air.

Calculation of required heat power is based on the information about volume of heated premises, difference between air temperature outside and required temperature inside the premises and dispersion coefficient (depends on the type of design and heat insulation of the premises). For the conditions of administration and service building of one of the Kryvyi Rih's mine the calculation gives a value 1264 kW. The production buildings of the mine's crushing section and workshops require approximately the same amount of heat power as the above mentioned administration and service building, i.e. 1264 kW. Without heat consumption for hot water supply, the total calculated power for heating will make 2528 kW. The available statistics shows that the heat power for hot water supply is approximately equal to the power required for heating – 2600 kW. The total calculated heat power for hot water supply and heating will consequently equal 5128 kW.

In 2013 the mine's boiler station consumed 6361,95 thousand m^3 of gas, i.e. the necessary amount of heat made 51213,7 Gcal (gas caloricity of 8,05 Gcal/1000 m^3 was taken as the basis for the calculations). To fully refuse gas consumption for the mine it is necessary to install heat pumps with total power of 5846312,785 kcal·h (6798,04 kW).

The divergence of over 1500 kW of the required heat power testifies unpractical use of heat at the mine (bad heat insulation of buildings, heat pipeline system, low boiler station efficiency, etc.).

The next step is to determine the possible heat power from mine waters and air and select heat pumps.Heat pump power is determined from the mine water volume consumption:

$$Q_{t(water)} = L_{(w)} \cdot p_{(w)} \cdot c_{v(w)} \cdot \Delta t_{(w)}, \tag{1}$$

where $L_{(w)}$ – water volume consumption, m^3/h; $c_{v(w)}$ – the specific heat of water, kW·h/kg K; $p_{(w)}$– water density, kg/m^3; $\Delta t_{(w)}$– difference between intake and returned water temperature, K. For the

conditions of considered mine the calculation gives a value 3923 kW.

Air heat pump power is determined from volume consumption of mine ventilation air:

$$Q_{t(air)} = L_{(a)} \cdot p_{(a)} \cdot c_{v(a)} \cdot \Delta t_{(a)}, \qquad (2)$$

where $L_{(a)}$ –air volume consumption, m^3/h; $c_{v(a)}$– specific heat of air, kW·h/kg K; $p_{(a)}$– air density, kg/m^3; $\Delta t_{(a)}$– intake and returned air temperature difference, 12K. For the conditions of considered mine the calculation gives a value 4700 kW.

This power is utilized by heat pumps in ventilation shafts. Considering the fact that a heat pump is also placed in the cage shaft where air is intaken, the utilized power can double and then the total amount of power utilized by water and air pumps will make 13322,594 kW.

At the stage of a pilot project it is only reasonable to use part of the great amount of possible power to be obtained from ventilation flows, i.e. to install 2 heat pumps of 1000 kW each in a cage shaft airflow: one 400 kW pump – at the ventilation station 'Severnaya' (Northern) and one 1000 kW pump – at the ventilation station 'Flangovaya' (Flank). This is because of the fact that the ventilation stations are located far from the mine's infrastructure and heat energy use requires building pipelines for heat transfer.

The ventilation station 'Flangovaya' is located near a large greenhouse that is a potential heat consumer. Besides, the station is about a hundred meters away from the ward boiler station 'Leninskaya' and in the future, by arrangement with the city heating plant, the mine can sell heat to the city. Three heat pumps of 1000 kW (or 6 of 500 kW) each can be installed to utilize mine waters energy. At that, the total power of water and ventilation air heat pumps will make 6400 kW.

Calculations show that needs for heat power for heating the mine's surface buildings and supplying hot water can be satisfied in full measure. The potential of using LPHE is almost twice as big and can be realized after installing additional pumps. In case of building additional pipelines within the city heating system, bigger part of the power from LPHE sources can go for heating residential buildings or other objects

within the service area of the boiler station 'Leninskaya' of the city's centralized heat supply system.

To satisfy needs for heating of the mine's buildings and neighboring buildings of the 'Leninskaya' boiler station service area, twelve 500 kW heat pumps and one 400 kW pump are installed. Territorial arrangement on sites with mine water and ventilation air carriers is made as mentioned above (see Fig. 1).

For realization of the described system can be used WaterkotteDSheat pumps (Germany), that are the most powerful on our market [12]. They are mostly used in powerful heating systems – for public buildings, shopping malls or large industrial premises. Pumps of these series are easily serviceable, operationally and environmentally safe, powerful and economical. The standard features and options, such as water heating system (a vertical accumulative tank on the heating side, a water heater, a temperature sensor, a three-way valve), the remote control, the software for visualization, the software for telemechanical devices, the sensor in the control premises, natural cooling ensure controlling the system conveniently.

It is also advisable pay attention to the products OilonChillHeat [13]. The range of their application is expanded through numerous options to adapt the same product for different applications. Modules for system extension structurally identical and allow you to add groups of pumps and valves to the base unit.

To ensure the effective functioning of described complex of equipment it is expedient to implement an automated process control system of utilization of low-temperature energy of mine water and ventilation air. Given the territorial distribution of control objects the system should be decentralized and realized on the basis of appropriate hardware. As shown in Fig. 1, the local PLCs are used for control the heat pumps installed on central cage station, ventilation stations 'Severnaya' and 'Flangovaya'. Information from local controllers is transferred to the controller hub, which solves the problem of optimizing control of the entire complex of equipment for heat power

generation, depending on the current needs of the   enterprise in heat energy.
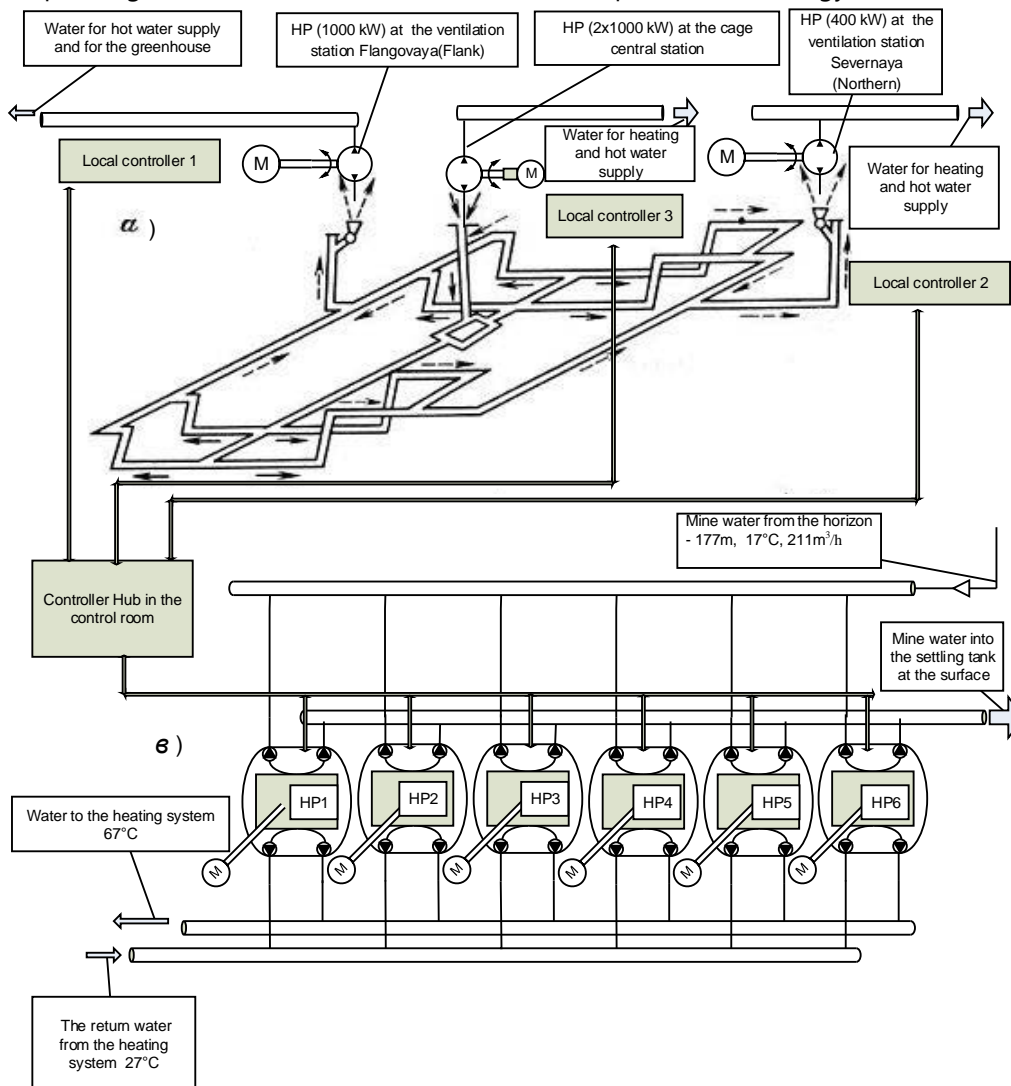

Figure 1.The diagram of installing heat pumps at an iron ore mine
a) air-water heat pumps in the mine's ventilation shafts;
b) water-water heat pumps in the mine's water pumping system.

The diagram does not show heat pumps that are installed at elevations below 1000 m in the mine and intended for local cooling of the ventilation air, which may have a temperature in this zone above 300 °C. These pumps are also included in the total distributed system for utilization of low-temperature energy and climate control in the mine.

In addition to the main heating system the project envisages the following solutions for heating and cooling buildings:

- water heating system (which includes: a vertical storage tank on the side of the heating, water heater, temperature sensor, three-way valve);

- remote control (external terminal);

- visualization software (PC connection to the RS 232);

- software for telemechanical devices (telephone modem, software with access protection);

- sensors in the control premises;

- supervisory control of the amount and mode of operation of the heat pumps of all complex for utilization of low-temperature energy of mine water and ventilation air.

Control of heating system is carried out using the latest generation of microcontroller. With a few sensors, located in the heat pump circuit, the constant diagnostics of the contour is carried, so that the abnormal operating condition is detected

in advance and the message about this situation is sent before the system fails. All tasks related to control (depending on the outside temperature with the control of control room), supervision and self-testing are performed. The system provides for the retention of data in the event of failure, etc. through the RS-485 interface for external terminal and RS 232 for remote control system, for example, using a telephone modem (for remote heat pump of mines ventilation system).

To solve the problems of optimal control of processes of utilization of low-temperature energy of mine water and ventilation air, the automation system consists of sensors for measuring evaporation pressure and condensation pressure, as well as sensors for measuring temperature in all contours, outside temperature, temperature in the control room and temperature of technical water. Adjusting the power of each pump separately is available either in a stepwise manner at two positions (75/100%) or smoothly, given that motors of compressors will be equipped by frequency converters .When you adjust power the limit of the operating range on the side of the heating can be reduced by 10 K.

Automation ensures energy efficiency and achieving maximum of coefficient of efficiency, optimization separate or combined production of heat and cold.

To ensure a reliable and versatile communication between different systems, hardware base of automation system must be selected for the conditions of maintaining the format of most common field buses (Modbus, Profibus, Profinet, Ethernet). Interfaces of field buses offer great opportunities for remote control, programming and acquisition of technological data, as well as provide a versatile reporting and high-quality monitoring of the processes dynamics.

The remote controlling and programming ensures reliable operation, reduces the cost of maintenance and support as well as facilitates subsequent modification of complex.

The whole set of equipment required for the processing of mine water and air streams, presents a distributed system that performs a common task of heating premises of the mine and hot water supply of domestic premises. Due to the fact that the flow of mine water is unstable, as well as the ambient temperature is changed, there arises the problem of adapting to these conditions. This problem lies in the discrete control of the amount of operating heat pumps, as well as in the smooth regulation of the generated thermal capacity of each machine. The reason is that heat pumps are limited in the control range without loss of efficiency. Similar problems are solved at different stages of the ore extraction and its processing [7, 13–15]. The most appropriate control system for this complex is a SCADA (supervisory control and data acquisition) system with displaying models of processes of the complex on a screen of the operator's station.

To solve the problem of optimal control of the process of generation and utilization of low-temperature energy of mine water and ventilation air is necessary to obtain an adequate mathematical model of the process. To do this, on the first stage of work is necessary to have tools to collect data about the functioning the system in different modes. From this point of view, the SCADA system is also the best solution.

For this purposes work is underway on develop a system of supervisory control and data acquisition, which will display the status of the process equipment and the values of regime parameters of heat pumps, as well as collect data for further analysis.

Fig. 2 shows one page of developed SCADA for visualization of the state of the heat pump for the utilization of low-temperature energy of mine water (air). The system displays values of the temperature of the heat pump, the evaporation pressure and the condensation pressure, the electric power consumed by the compressor, heat power generated by the heat pump, the state of the equipment (pumps, compressors, valves, tank).

Results. The pilot project implementation effect:

- reduction of gas consumption due to operation of heat pumps on 6000 thousand m^3 a year (at the cost of gas of 4,02 UAH/m^3 the annual amount for gas consumption at a boiler station will make UAH 24,12 mln or 1,5075 mln EUR);

- reduction of atmospheric emissions by over 100 t/year;

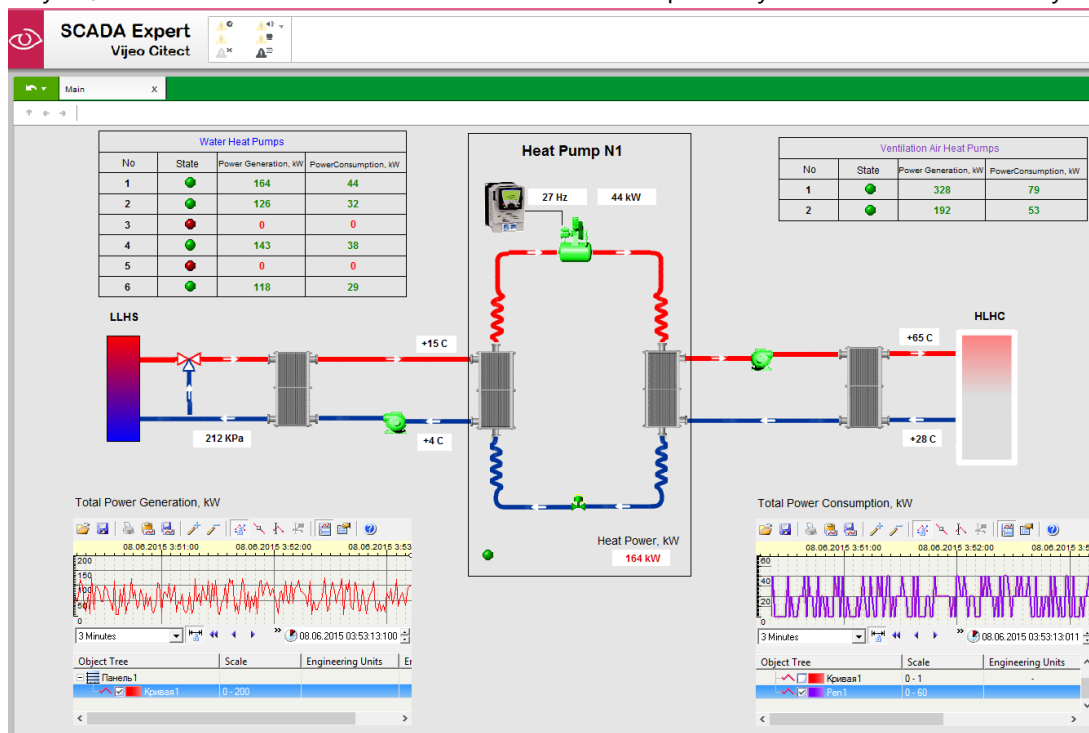- reduction of thermal pollution of the atmosphere by over 20 thousand Gcal/year.

Figure 2. Visualization of the state of the heat pump for the utilization of low-temperature energy of mine water

The amount of financing (the project and implementation) will make about 1810 thousand EUR. Taking into account electric power costs increase (982094 EUR in a year), the annual effect from implementation of the project will amount over 427906 EUR.The payback period of the project is 4 years and 3 months.

Conclusion. The results of the development of initial materials for the conceptual design of the automated distributed system for utilization of low-temperature energy of mine water and ventilation air on the basis of the technology of heat pumps for hot water supplying of mining premises on the surface and improving the microclimate of working area miners in deep horizons of mines are presented.

References.

1. European Heat Pump Market and Statistics Report. Available at:http://www.ehpa.org/about/news/article/european-heat-pump-market-and-statistics-report-soon-available/.

2. Outlining the role of heat pumps in energy and cost efficient nearly zero energy building solutions in Finland. Available at: http://www.ehpa.org/about/news/article/outlining-the-role-of-heat-pumps-in-energy-and-cost-efficient-nearly-zero-energy-building-solutions/

3. The European Heat Pump Association (EHPA) represents the majority of the European heat pump industry. Available at: http://www.ehpa.org/about/

4. IEA-ECBCS Annex 48 : Heat Pumping and Reversible Air Conditioning. Available at: http://en.wikipedia.org/wiki/IEA-ECBCS_Annex_48_:_Heat_Pumping_and_Reversible_Air_Conditioning.

5. Analysis of building heating and cooling demands in the purpose of assessing the reversibility and heat recovery potentials. Available at: http://www.iea-ebc.org/fileadmin/user_upload/docs/EBC_Annex_48_Final_Report_R1.pdf.

6. Review of heat recovery and heat pumping solutions. Available at: http://www.iea-ebc.org/fileadmin/user_upload/docs/EBC_Annex_48_Final_Report_R2.pdf.

7. IEA 48 Simulation tools: Reference book. Available at:http://www.iea-ebc.org/fileadmin/user_upload/docs/EBC_Annex_48_Final_Report_R3.pdf.

8. Italy Case Study N°3: Office / industrial building with GSHP with phase-change hot and cold storage. Available at: http://www.iea-ebc.org/fileadmin/user_upload/docs/ EBC_Annex_48_Case_Study_I3.pdf.

9. Marsh L.S., Singh S. (1994). Economics of Greenhouse Heating with a Mine Air-assisted Heat Pump. *Transactions of the ASAE* **37**(6), 1959-1963. doi:10.13031/2013.28288.

10. Kolomiets O.P. Tselesoobraznost ispolzovaniya nizkopotentsialnoy teploty shakhtnykh vod i ventilyatsionnogo vozdukha dlya obespecheniya teploenergeticheskikh

potrebnostey predpriyatiy podzemnogo Krivbassa. *Razrabotka rudnykh mestorozhdeniy*, **93**, (2010).

11. Banks D., Skarphagen H., Wiltshire R., Jessop C. (2004). Heat pumps as a tool for energy recovery from mining wastes. *Geological Society*, **236**: doi:10.1144/ GSL.SP.2004. 236.01.27.

12. Waterkotte. Heat Pumps Product Range. Available at: http://www.waterkotte.de/uploads/media/Lieferprogramm _Prospekt_E.pdf.

13. OilonChillHeat. Optimized cooling and heating performance. http://www.oilon.com/uploadedFiles/Scancool/ Products_and_Services/Brochures/Oilon_Scancool%20esite_en_s creen.pdf.

14. Morkun V., Tron V. (2014). Ore preparation multi-criteria energy-efficient automated control with considering the ecological and economic factors, Metallurgical and Mining Industry, **5**, 4–7.

15. Krutov G., Savitskyi A. (2014). Economic evaluation of efficiency of investments into energy-saving controlled electric drives of conveyers of mining and processing works. Metallurgical and Mining Industry, **6**, 78–81.

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SYNTHESIS OF HEAT AND POWER UNIT AUTOMATIC CONTROL SYSTEMS

Yefymenko L., PhD, Associate prof., Tykhanskyi M., PhD., Associate prof.,

Dmytruk V., M.d. student

Kryvyi Rih National University

Abstract. The process of synthesis of heat and power unit automatic control systems is studied in the article. A review of works and publications showed that implementation of management theory modern methods in relation to heat and power units is restrained by sophisticated workflow mathematical models in power units' elements. Different types of automatic control are delineated using a steam boiler as an example.

Keywords.

Introduction. Modern water heating units for heating energy generating in heat and power systems are known to be complex technical systems. That's why it is difficult to control their parameters automatically for optimum operation mode control [1]. Various approaches, methods and means are used to work out this engineering task nationally and internationally.

It is extremely important to conduct theoretical and practical research in physical and mathematical stimulation to develop power industry. Theory and principles of power equipment models' organization and their regulation systems were worked out to enable workflow stimulation in large power systems.

Most heat power stations display concern about automatic control and management systems modernization whose hardware equipment has exhausted technical resources, is out of date and should be replaced as soon as possible. Current regulators do not meet up-to-date requirements and, therefore, their further maintenance without being replaced or improved will be economically unsound.

The aim of the paper is to analyze the automatic control system synthesis methods for power and substance transformation in heat and power units using mathematical models.

The issue of boiler unit automatic control, management automatic system synthesis and heat and power units' mathematical models development is justified by a great number of respectful national and international scientists [1-18].

Introducing computer equipment on the basis of microprocessors has had a great impact on a general approach to organization and tasks of boiler units and hot water boilers maintenance. This issue is investigated in the works of I.V. Plachkov, A.K. Shydlovskyi, B.S. Stohni, M.M. Kulyk, O.S. Dupak. For instance, level control systems in a boiler barrel have undertaken great transformations from a simple level float regulator and single-pulse regulator with hydrostatic level control to the widespread regulator with impulse circuit. Microprocessors allowed level regulating using a mathematical model. Such mathematical models for boiler units and hot water boilers include description of combustion behavior and heat exchange characteristics as well as the boiler's general dynamic linking.

In this paper we will consider current approaches, methods and means of heat and power unit automatic control.

The analysis of current methods and means of heat and power unit automatic control gives grounds to create an approach for workflow control tasks in heat and power industry.

Materials and Methods. The synthesis of heat and power unit automatic control systems is studied in the paper.

Expert system of control algorithms for power generation units has been developed by Moscow engineering institute scientists. Also hot water boilers control systems have been investigated as well as their optimization, having little information about unit models [2]. The authors argue that recent works on automatic

control theory are focused upon so called Fuzzy-control with unknown mathematical model. Such type of control is based on L.A. Zade's fuzzy-set theory [3], having expert evaluation as basic material. However, the authors state that the above-mentioned approach is limited in use in power industry. Hence, they considered an alternative complex of automatic control methods for units with unknown mathematical model. They approved the efficiency of expert evaluation which is based on modified adaptative methods.

The exercise of requirements for energy saving and heat and power unit environmental improvement is displayed in the paper [4]. Furthermore, mathematical models of continuous and discrete control systems of efficiency and ecological cleanness of power and hot water boilers are investigated in more detail. It is proved that under essential delay in optimum parameter measurement circuit (i.e. incomplete combustion constituents in flue gases) the use of the discrete system in order to adjust the "fuel" and "air" correlation provides higher dynamic accuracy in the field of real disturbing frequencies than the continuous one. Although, high control stability and a boiler's economic and environmental indices optimization are attained.

The authors study the grapho-analytical method to design an optimum algorithm for hot water boilers automatic control working for overall load [5]. The analysis begins with a simple case of load sharing between two similar boilers and comes to a general case for different boilers. Basic data is the dependence of the boilers' coefficient of efficiency on their loads. The formula of fuel economy estimate using discrete control optimum algorithm is given in the paper. The formula is used for different boiler units working at full capacity.

There is a description of Boilermizer scheme in the paper [6] developed by Energy Technology Control (Great Britain) with microprocessors for "air" and "fuel" correlation control in hot water boilers having heat production of (0,63-6,3) GJ per year and being liquid fuel or gasoline-based.

The authors [7] also study combustion automatic control system in hot water boilers,

which was developed in Great Britain, with keeping CO in flue gases. Besides, the authors state that combustion control in terms of oxygen is imprecise since it is difficult to define the representative point of gas samples screening. The scheme studied, automatic control discrete algorithms and testing data for the three boilers working on oil and natural gas are elaborated in the paper. It is shown that the boilers' coefficient of efficiency has increased up to 0, 5-3%, oxygen content in flue gases has decreased from 4-5 % to 1,4-2,8%, emissions have decreased by 25%.

Different strategies of US boilers automatic control systems organization in terms of their optimized efficiency are investigated in the paper. Key factors for ACS design are dynamic properties of a unit and closed-loop system. There is a description of a typical boiler's ACS and its separate circuits in the paper. In-depth analysis of excess oxygen control in order to minimize air excess and flue gases temperature at zero underburning is given. The methods to determine flue gases content and parameter choice are considered in the paper which characterizes combustion process and fuel burnout rate. The most appropriate scheme for optimization is the one that uses O_2 and CO analyzing.

The automation system of heavy oil boiler houses developed in France is investigated in the paper [9]. To increase the coefficient of efficiency, to reduce costs and to decrease environment pollution level the author suggests the following ways of boilers' automation: using of application-specific logic blocks (schemes) in programmed automatic units in multiple control systems; applying of adaptive or remote viewing systems which allow full or partial excluding a person's involvement in a boiler house; installing some water-fuel slurry automated devices on a burner fuel feedline to decrease carbon loss.

The authors reviewed English industrial systems applied to automatically control gas fuel and flame loss in hot water boilers [10]. Those systems allow determining gas and oxidizing agent loss. They are used to automate continuous heat generation under variable gas mixture combustion.

In this paper the authors study the design and functions of the Japanese low-mass and hot water boiler computer-driven control system [11]. The system which is based on conventional detectors like combustion detectors, pressure switches, is provided with some additional functions. Moreover, there is an opportunity to detect a boiler's status and the system of control, processing, data storage, data printing release and its transfer via data channel to a maintenance panel.

Optimum algorithm determination method to control boilers in a boiler house grounded on dynamic programming methods is suggested by the authors [15] and is successfully employed in Russia. The method given is based on optimum correlations of the efficiency coefficient and boiler house production acquired by statistical analysis. It is of general usage and can be adapted to any kind of boilers. Besides, it can be used to control boiler production manually and automatically considering any operating boiler design.

Gain in hot water boiler performance by means of air feed automatic control system using the "fuel" and "air" correlation is of great importance. The paper gives the description of such system [16] which, according to their authors from Australia, is thought to save up 2% of the fuel. Although the system is designed for shell boilers with rotary burners, it can be used for hot water boilers as well. The system uses a zirconium oxide based detector which measures O2 content in flue gases with given values referring to unit loads, an executing mechanism changing air feed. In case of inability to measure O2 content (under essential air inflow), air-flow and fuel detectors connected to a comparison unit are used.

The Swiss design shows that gas saving in central heating boiler units the burners should have two- or multistep control and to decrease the number of their ons and offs there should be a heat accumulator between a boiler and a circuit [17]. To use flue gas heat there should be a heat exchanger behind a boiler to heat water for hot water supply. Boiler load control should be done in accordance to the temperature of the water having passed through a boiler. Applying the above-mentioned measures of saving in terms of a test boiler showed 37% of gas saving.

Results. The analysis of the above-mentioned and some other current approaches, methods and means of boiler house parameters automatic control at hot water and combined plants revealed that, in spite of their diversity, all of them are focused on temperature or hot water (steam) pressure automatic control; optimum correlation between burnt fuel amount and air losses; exhaust in a combustion chamber and behind a boiler and CO abatement decrease. The last matters very much for the decline of harmful matters in the products of combustion and contamination of environment.

One of effective methods of improvement of quality of smoke gases and energy-savings there is automation of processes of burning of fuel in boiler rooms. Perfection of process of burning of fuel is determined by the economy of work of the caldron setting and instrumental in protecting of environment from contamination. It is known that the serve of fuel and air in heating of caldron must be carried out in certain correlation both insufficient and surplus, serve of air reduces an output-input of caldron ratio [13]. In order that processes of burning, which take place in the caldron settings, as least contaminated an atmosphere, it is necessary to equip the system of the automated management a subsystem for the improvement of quality of smoke gases. For solving of the noted task CAS must additionally execute the followings functions [13]:

- automatic collection of values of parameters of processes of burning, which influence on quality of smoke gases;

- analysis of the got values of the controlled parameters of technological processes of burning;

- automatic control parameters which provide necessary nedopal;

- determination of supernumerary situations, that exceeding of possible maintenance of the harmful pluggings is in smoke gases.

Automation of caldron aggregates foresees the equipment of every caldron facilities of automatic control and measuring of his

parameters, automatic defence, in case of occurring of emergency situations and providing of the automated management a separate aggregate.

Conclusion. Requirements for hot water unit energy saving and environmental improvement are directly connected with current production processes improvement based on modern control theory methods. To bring in modern control theory methods by means of multilink systems one should have an adequate production process mathematical model to converse energy in the form of a conventional differential equations system. Dynamic mathematical model design is complicated both by the distribution of most separate subprocesses in hot water units and by difficult choice of physical parameters being a part of differential equations.

The discussed structures, approaches and boiler automatic control systems can be used to develop the projects of their automation using a wide range of mathematical methods of process parameters control.

References:

1. Artyukh S.F., Duel M.A., Shelepov I.G. Osnovy avtomatizirovannyh sistem upravleniya energogeneriruyushchimi ustanovkami electrostantsii [Basics of automatic control systems with power plant energy generation units],Kharkov: Znanie, 1998.

2. Gorbachevskij V.V., Sudakov A.V., Levchenko A.I. (1999). Voprosy povysheniya ekonomichnosti raboty energoblokov bol'shoy moshchnosti, *Energetika i elektrifikatsiya*, **2**, 1–5.

3. Gorelik A.Kh., Duel M.A., Orlovskij V.A. (2000). Napravleniya razvitiya i modernizatsii ASU energoblokami TES i AES, *Energetika i elektrifikatsiya*, **3**, 28–31.

4. Davudov N.I., Idzon O.M., Simonova O.V. (1995). Opredelenie paramertov nastroiki PID–regulyatora po perekhodnoi kharakteristike obekta regulirovaniya *Teploenergetika*, **10**, 17–22.

5. Dryuchin V.G., Potapova A.V. (1999). Sintez regulyatorov sistem upravleniya nelineinymi i lineinymi obektami, *Vestnik MANEB*, **10**(22), 100–104.

6. Duel M.A. (1999). Uchyot osobennostei blokov TES i AES kak obektov upravleniya pri sozdanii ASU energoblokami, *Energetika i elektrifikatsiya*, **7**, 20–25.

7. Duel M.A. Avtomatizirovannye sistemy upravleniya energoblokami s ispol'zovaniem sredstv vychislitel'noi tekhniki, Moscow: Energoizdat, 1983

8. Duel T.L. (2000). Ekonomicheskaya effektivnost ASU energoblokami, *Trudy In. Mash. NAN Ukrainy*, 156–161.

9. Klyuev A.S., Tovarnov A.G. Naladka sistem avtomaticheskogo regulorovaniya kotloagregatov, Moscow: Energiya, 1970.

10. Kondratev V.V., Mazurov V.M. (1994). Bystrodeistvuyushchij adaptivnyj PID–regulyator s nastroikoj parametrov po metodu Tsyglera – Nikolsa, *Teploenergetika*, **10**, 10–16.

11. Lebedev A. T., Gushlo V. N. (1971). Analiticheskij metod raschyota promyshlennoj sistemy avtomaticheskogo regulirovaniya na zadannyj pokazatel kolebatelnosti, *Teploenergetika*, **8**, 79–81.

12. Yefimenko I.I. (2011). Avtomatyzatsiya protsesiv gorinnya palyva v kotlah, yak vysokoefektyvnyj sposib znyzhennya teplovogo i himichnogo zabrudnennya atmosfery, *Journal of Kryvyi Rih Technical University*, **28**, 32-35.

13. Zamytskyi O.V., Yefimenko I.I. (2012). Modernizatsiya systemy avtomatychnogo keruvannya rezhymamy roboty kotla, *Journal of Kryvyi Rih Technical University*, **30**, 168-171.

14. Yefimenko I.I., Zamytskyi O.V. (2012). Analiz isnuyuchih rezhymiv spalyuvannya pryrodnogo gazu, *Journal of Kryvyi Rih Technical University*, **30**.

15. Pletnyov G. P. Avtomatizirovannoye upravleniye obyektami teplovykh elektrostantsyi, Moscow: Energoatomizdat, 1999

16. Potapova A.V. Algoritm avtomatizirovannoj nastroiki regulyatorov v sistemakh upravleniya, Alchevsk: NIPKI "Parametr", 2008.

17. Raibman N. S. (1999). Identifikatsyya obektov upravleniya, *Avtomatika i telemekhanika*, **6**, 80–93.

18. Khmelyova A.V., Kotsemir I.A. (2000). Avtomatizirovannaya nastroika dvukhkonturnykh sistem regulirovaniya teploenergeticheskikh protsesov, *Vestnik SUDU*, **9**, 120-124.